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Radical Innovations and long waves into Pasinetti's model of structural change : output and employment

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SUMMARY

1. This paper introduces long waves into Pasinetti's model of structural change on the assumption that productivity growth is fundamentally driven by technological revolutions. Radical process innovations produce a leap in productivity for the innovator and progressively extend to the sector according to a non-linear path. Demand for completely new products follows a similar profile, which is determined by the product life cycle.

The argument is developed at the logical stage of the "natural" system, focussing the investigation mainly at the sectoral level.

2. Three general results should be mentioned:
(i) the overwhelming importance of the pattern of diffusion of the technological revolution. It is, in fact, this element that shapes the productivity curve of the sector, which in turn determines the trend and form of the price movement as well as the scope for the growth of demand;
(ii) the pattern of demand which, for process innovations, results from an endogenous price and income mechanism set up by the technological revolution;
(iii) the importance of price and income elasticities of demand, which can amplify or reduce the basic impetus coming from productivity.

3. More specifically, the sectoral analysis for process innovations shows that physical output in the final sectors follows a long-wave (S-shaped) profile while, in the capital goods sectors, it shows a cyclical pattern around the long-wave path displayed by the corresponding final sector.

The inter-sectoral diffusion of such innovations sets in motion a cumulative process of growth bringing the system out of the long stagnation.

4. The employment outcome is complex.

(a) The clearest case is that of product innovations, which show a growing employment trend both at sectoral and global level.

(b) For process innovations the results are more uncertain because employment is subject to a number of conflicting forces. Particular mention should be made of the price and income elasticities of demand and the degree of mechanization of final sectors.

(b.1) At the sectoral level it appears that, in the most common cases, a substantial growth of output may very well be compatible with stagnating or even declining employment.

(b.2) At the macroeconomic level the outcome is even more uncertain, because it depends on the relative importance of the sectors which remain unaffected by the radical technological change. If their share of the total economy is limited, then the prevailing macroeconomic tendency could be a very slow increase or even stagnation in employment, including during the long expansion.

5. The theoretical analysis of this paper has at least three implications for economic policy: (i) on how to promote diffusion of the technological revolution; (ii) on the actions to be taken on the employment front; (iii) on the guiding role of public authorities in meeting the equilibrium condition for wages, which links wages to the average productivity growth of the system.

I. INTRODUCTION

In this paper an attempt is made in order to develop Pasinetti's (1981) model of structural change by introducing into it technological revolutions in order to derive the changes over time in physical output and employment. In Pasinetti's model technical change, although taking place at a different pace in the various sectors, remains exogenous, in the sense that it is not the result of the normal functioning of the system. Here I go a step further and postulate that, in line with the long-wave theory, the most salient feature of technical change is the periodic appearance of technological revolutions. These radical innovations entail a substantial leap in labour productivity for the innovator, then spread thorough the sector according to some diffusion function and eventually generate a complex dynamic in the system involving prices, quantities and employment.

My analysis assumes that the long-wave theory holds, and particularly the explanation in terms of technological revolutions (see Van Duijn, 1983). Although still controversial, the recent empirical work on the existence of long-waves in output (Metz, 1992) and innovations (Kleinknecht, 1990) has made this approach sound enough to justify my purpose.

To introduce the argument, I recall here some general characteristics and results of Pasinetti's model that are my starting-point. Further analytical details are summarized in Appendix I.

II. THE STARTING-POINT: PASINETTI'S MODEL OF STRUCTURAL CHANGE

1. General features of the model

1.1. Faced with a reality which is extremely complex, the social scientist is obliged to make drastic simplifications if he is to distinguish that which is essential in order to understand such reality from that wich is of secondary importance. The theorizing process is thus "a sort of telescope, which is used in both directions: to magnify, in one direction, those aspects on which the theorist has chosen to concentrate; and to shrink, in the opposite direction, ... those aspects that are to play a secondary role" (Pasinetti, 1986. b, p. 428). Pasinetti's model represents a return to the classical tradition of the "production" approach.

With a view to studying the long-term dynamics of capitalist economies as well as income distribution and the relations between social classes, the classical economists deemed that, of the two main economic activities - production and exchange - the former was by far the most important. They thus emphasized the reproducibility of commodities: each individual commodity can be made available in unlimited quantity provided that we devote enough resources to producing it. Of course, they did not ignore exchange and the "scarcity" connected with natural resources, but they attached much less improtance to these aspects than to production. Sraffa (1960) - another distinguished exponent of the classical approach - has identified the role played by land and natural resources by showing that they influence neither the price of the "basic" commodities [1] nor the profit/wage relationship.

1.2 The classical tradition is also the inspiration for the methodological device of the "natural" system: Pasinetti works out his model by studying "the 'primary and natural' determinants of the variables characterizing an economic system",[2] which are prior to, and independent of, any institutional set-up (Pasinetti, 1981, p. 149). "The [theoretical] problems... that emerge at this stage are either in terms of necessary relations, if certain goals are to be achieved (e.g. full employment, price stability, etc.), or in terms of logically consistent relations, or in terms of normative rules, or in terms of those problems which are generated by the basic forces at work in a dynamic context" (Pasinetti, 1994, p. 41). All these relations can be developed without referring to specific behavioural and organizational assumptions; they reflect the basic characteristics of any modern industrialized economy.[3] Of course, this gives only an initial picture which has to be fleshed out with an analysis of the institutions.

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1 *By "basic" commodities Sraffa (1960) means the commodities that are required, directly or indirectly, for the production of all commodities.*

2 *For a discussion of Pasinetti's claim that the natural system is independent from institutions see Bortis (1993).*

3 *For Pasinetti, the "natural system" is not only a purely methodological device but has also a normative dimension because it characterizes a system with efficiency and fairness. This point is discussed in Reati (1994).*

1.3 Economic rationality is defined not in the usual narrow sense of profit maximization but rather as the "intelligent" process of learning: the discovery of new and better methods on the production side, and the awareness of alternative patterns of consumption and the formation of new preferences on the demand side.

The general principle of learning is not incompatible with the utilization, at some points in the analysis (such as the choice of technique), of the traditional principle of optimization. However, "the validity of the [model] remains unaltered even if the consumption or production choices are not strictly rational" [in the customary sense] since, in this case, "the coefficients simply represent the choices that have actually been made, whatever the process through which they have been made" (Pasinetti, 1981, p. 150).

1.4 The model accounts for structural change in a twofold manner. First, technical change takes place at a different pace in the various sectors of the economy. Second, the model is "open" in the sense that technical change implies the creation of new industries and the disappearance of others. Demand is explicitly introduced and plays a crucial role in determining the development of output. When real income per capita grows, the increase in demand for any final commodity *i* follows an Engel curve.

1.5 Pasinetti's model is an input-output model viewed from the point of view of vertical integration (Pasinetti, 1973; 1986.a). As explained in Appendix I, vertical integration is an algebraic transformation of the coefficients of the input-output table which focuses on the *final commodity* (instead of industry), showing what is directly and indirectly necessary in the whole economic system to produce it. The output of a final commodity is thus resolved into its two basic components: a flow of labour and a stock of productive capacity; all intermediate inputs are eliminated because they are subsumed by these two elements. More precisely, the vertically integrated sector for final commodity *i* is represented by an elementary vector with three elements :

$$[1 \quad 1 \quad v_i] \qquad (i = 1,2,\dots,m) \qquad (II.1)$$

where the first component refers to final commodity *i*, the second component to the vertically integrated productive capacity for *i* and the third component to the vertically integrated quantity of labour for *i*.

The vertically integrated *productive capacity* (hereinafter "productive capacity"), which is represented in a simple way by 1 in the above vector, is a composite commodity whose elements are derived from a column of the Leontief inverse matrix (see Appendix I for details). The productive capacity is thus a set of different types of physical goods taken in strictly defined proportions. Pasinetti (1980, p. 24) explains this concept saying that, "as a matter of fact, any commodity - for instance, a pair of shoes - can always be considered as composed of various elementary commodities - such as leather, string, rubber - put together in fixed proportions". The vertical integration approach implies, however, that the composition of the productive capacity is not stated in the model: productive capacities are considered only *in terms of the units required* to perform an activity.

For each final commodity *i* there is a specific unit of productive capacity.

Vertical integration is particularly suitable for dynamic analysis (Pasinetti, 1981, pp. 114-117). In fact, when an economy is subject to technological change, a model framed within the conventional input-output analysis is not easily manageable, because the inter-industry relations are constantly upset. The technical coefficients of the input-output table change radically and some of them disappear. Against this, the vertically integrated sector is much more stable. Let us refer here to the above-mentioned vector representing the vertically integrated sector. Technological change will influence only the labour coefficient v_i since, by definition, to obtain one unit of final commodity *i* it is always necessary have one unit of productive capacity. Even if the specific composition of this productive capacity is substantially modified by technological change, its labour content is quite stable. For instance, if there is the substitution of one input for another (e.g. some components of a car are made of plastic instead of steel), the labour coefficient will be only slightly reduced because the decrease in labour requirements for the old input (steel) will be partly compensated by the additional demand for labour for the new input (plastic).

In any case, since the vertically integrated coefficients are simply a linear combination of the direct input-output coefficients, it is always possible to move from one kind of analysis to the other by using the Leontief inverse matrix. This should be done when the failure to take account of the inter-industry relations implied by vertical integration conceals some important parts of the process.

2. *Basic structure*

2.1 Pasinetti (1981) considers three cases of a closed economy with no joint production: (i) a "pure labour" economy in which production is carried out by labour alone; (ii) an economy in which the final commodities are produced by means of labour and capital goods; (iii) a more complex model involving capital goods for the production of capital goods[4]. In Pasinetti (1981) the focus is on the second model because it is relatively simple from an analytical view point but still yields all the results that could be derived from the third model. In spite of this, I shall here consider the third model because, if long waves are to be introduced into Pasinetti's model, it is not possible to assume that capital goods are produced by labour alone.

2.2 The economy comprises three sets of sectors :

sectors *i* (i = 1,2,...,n-1), concerning the production of *final commodities;*

sectors k_i, producing the *capital goods* required by final sectors *i* as well as by the capital goods sector itself to replace the capital goods which wear out, and to increase productive capacity;

sector *n*, which is the *households* sector : it provides the labour force for sectors *i* and k_i and receives final commodities as well as capital goods for new investments.

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4 *International economic relations are analyzed in the two final chapters of Pasinetti (1981 and 1993)*

2.3 The balance of each sector in terms of *flows* of physical quantities is as follows :

α) ***sectors i***

inflows :

x_{ni} units of labour

$x_{k_i i}$ units of productive capacity for the capital goods used up during the current year

outflows

x_{in} units of commodity *i*

β) ***sectors k_i***

inflows

x_{nk_i} units of labour

$x_{k_i k_i}$ units of productive capacity to replace the capital goods used up during the current year.

outflows

$x_{k_i i}$ units of productive capacity for sector *i* to replace what is used up during the current year

$x_{k_i k_i}$ units of productive capacity for sector k_i itself to replace the capital goods used up during the current year

$x_{k_i n}$ units of productive capacity for net investments for sector *i* and for sector k_i (to provide the capital goods required by the expansion of sector *i*)

γ) ***final sector n***

inflows

$\sum_i x_{in}$ units of final commodity *i*

$\sum_i x_{k_i n}$ units of productive capacity for new investment (for sectors *i* as well as for sectors k_i)

outflows

$\sum_i x_{ni}$ units of labour for sectors *i*

$\sum_i x_{nk_i}$ units of labour for sectors k_i

Taking :

X_{k_i} as the physical output of sector k_i (in terms of the number of productive capacities),

X_i as the physical output of sector *i*,

X_n as total population, which, for the time being, is supposed to be equal to total labour supply,

then the flow structure of the system is :

$$X_i = x_{in} \qquad (i = 1,2,...,n\text{-}1) \qquad \text{(II.2)}$$
$$X_{k_i} = x_{k_i i} + x_{k_i k_i} + x_{k_i n} \qquad \text{(II.3)}$$
$$X_n = \Sigma_i x_{ni} + \Sigma_i x_{nk_i} \qquad \text{(II.4)}$$

2.4 At the beginning of each period, there is a *stock* of productive capacity inherited from the past, which is represented by the vector :

$$[K_1, K_2, ...K_{n-1}] \qquad \text{(II.5)}$$

where K_j is the *number* of units of productive capacity required as stock by sector j (j = 1,2,..., n-1)

According to the definition of vertically integrated sector (Formula II.1), the number of units of productive capacity in each of these sectors must be equal to the number of units of the commodity produced: final commodity i and the capital goods for i. To express X_{k_i} in a homogeneous way with respect to the final commodity to which it refers, Pasinetti (1981, p. 43) introduces the technical coefficient γ_i for the capital goods sector. So as not to go on *ad infinitum*, Pasinetti (1981, p. 43) assumes that each sector k_i produces capital goods for itself and for the corresponding final sector i according to a fixed proportion γ_i. More precisely, γ_i is the ratio of the number of units of consumption goods to the number of units of capital goods which can be produced by the same unit of productive capacity. In other words, the "machine" is the same, and it can produce x_i physical units of the consumption goods i or $[(1/\gamma_i)\, x_i)]$ units of capital goods for i (i.e. the productive capacity itself). This makes it possible to fix the number of units of productive capacities required by sector k_i (K_{k_i}) in terms of i equivalents as: $\gamma_i X_{k_i}$. In sum, we have:

$$K_i = X_i \qquad \text{and} \quad K_{k_i} = \gamma_i X_{k_i} \qquad \text{(II.6)}$$

2.5 Equations (II.2) to (II.4) can be rewritten in terms of the technical coefficients a_{ij}, defined as :

$$a_{ij} = x_{ij} / X_j \qquad a_{ij} > 0; \qquad i, j = 1,2,...,n \qquad \text{(II.7)}$$

Thus:

a_{ni}, a_{nk_i} are respectively the quantity of labour per unit of physical output in sectors i and k_i;

a_{in} is the per capita demand for final commodity i;

$a_{k_i n}$ is the new investment *per capita*.

As regards the physical flows of depreciation, let us assume that, in each sector, a *constant* proportion of the productive capacity is used up as a result of normal wear and tear, i.e. :

$$a_{k_i i} = 1 / T_i \qquad \text{(II.8)}$$

where T_i corresponds to the average physical life of capital goods in sector *i*.

Thus, the term $x_{k_i i}$ in equation (II.3) becomes :

$$x_{k_i i} = a_{k_i i}\ X_i = (1/T_i)\ X_i \qquad \text{(II.9)}$$ [5]

Since, for sector k_i , the number of units of productive capacities required is expressed in tyerms of *i* equivalents, the physical depreciation for this sector ($x_{k_i k_i}$) is:

$$x_{k_i k_i} = a_{k_i k_i}\ \gamma_i\ X_{k_i} = (1/T_{k_i})\ \gamma_i\ X_{k_i} \qquad \text{(II.10)}$$

where T_{k_i} corresponds to the average physical life of capital goods in sector k_i.

Taking into consideration formulae (II.8) to (II.10), equations (II.2) to (II.4) for physical outputs and total labour supply are written as follows :

$$X_i = a_{in}\ X_n \qquad \text{(II.11)}$$

$$X_{k_i} = (1/T_i)\ X_i + \gamma_i\ (1/T_{k_i})\ X_{k_i} + a_{k_i n}\ X_n = $$

$$= C1_i \left[a_{k_i n} + \frac{1}{T_i}\ a_{in} \right] X_n \qquad \text{(II.12)}$$

$$X_n = \sum_i a_{ni}\ X_i + \sum a_{nk_i}\ X_{k_i} \qquad (i = 1,2,\ldots,n\text{-}1) \qquad \text{(II.13)}$$

where constant $C1_i$ is: $C1_i = T_{k_i}\ /\ (T_{k_i} - \gamma_i\ )$.

2.6 The price system is "dual" with respect to the system of physical quantities. To compute prices, Pasinetti (1981) follows the Sraffian tradition of assuming that wages are paid at the end of the production period. The wage bill is not, therefore, part of the capital advanced by entrepreneurs and the rate of profit is computed only on the stock of capital. The price system can be expressed in a way similar to equations (II.11) and (II.12). We have merely to define profits. For this purpose, let :

p_{k_i} be the price of a unit of productive capacity;[6]

π the rate of profit, taken as uniform to simplify notations.[7]

The unit profit is :

for sectors i :

$$(\pi\ X_i\ p_{k_i})\ /\ X_i = \pi\ p_{k_i}$$ [8]

---

5 *Let us remember equation (II.6) above, which expresses the productive capacity of each sector in terms of the output of the final commodity.*

6 *Being the price of a composite commodity,* p_{k_i} *is thus the weighted average of the prices of the capital goods constituting the productive capacity.*

7 *Note that there is no implicit assumption on a long term equilibrium rate of profit resulting from capital mobility. On the contrary, as we shall see later (paragraph 5), the "natural" rate of profit differs from one sector to another. Moreover, if instead of the "natural" system we consider real economies, there is nothing to prevent the introduction of a set of differentiated profit rates reflecting non-competitive market structures. This would complicate the results, which would though be of the same kind.*

for sectors k_i :

$$(\pi \gamma_i X_{k_i} p_{k_i}) / X_{k_i} = \pi \gamma_i p_{k_i} \quad {}^{9}$$

The price of any commodity (p_i or p_{k_i}) has a double component : the direct cost of production (the cost of capital goods used in the production period plus labour costs) and the unit profit. Indicating by *w* the (uniform) wage rate[10], we have :

$$p_i = (1/T_i)\, p_{k_i} + a_{ni}\, w + \pi\, p_{k_i}$$
$$p_{k_i} = (\gamma_i / T_{k_i})\, p_{k_i} + a_{nk_i}\, w + \pi \gamma_i\, p_{k_i}$$

Solving with respect to p_{k_i} in the latter equation and substituting into the former, we obtain :

$$p_i = [(\pi + 1/T_i)\, C2_i\, a_{nk_i} + a_{ni}]\, w \qquad (II.14)$$
$$p_{k_i} = [C2_i\, a_{nk_i}]\, w \qquad (II.15)$$

where $C2_i = T_{k_i} / (T_{k_i} - \gamma_i - \pi \gamma_i T_{k_i})$.

We obtain a very interesting result. We see, in fact, that the price of any commodity is formed by two terms : the term within brackets, which represents the technical coefficients and the rate of profit, and the wage rate. "This means that what appears in the square brackets, by being multiplied by the wage rate, must obviously be either a physical quantity of labour or something which is made to be equivalent to a physical quantity of labour. ... The prices thereby express a theory of value which is in terms of *labour equivalents*" (Pasinetti 1981, pp. 42-43). This is made possible by the vertical integration analysis.

2.7 The economic system can be written in matrix form as a *"closed"* Leontief model

$$(\mathbf{A} - \mathbf{I})\, \mathbf{X} = \mathbf{0} \qquad (II.16)$$

where

X is a column vector (*2n-1*) whose first *n-1* components are the X_i, the following *n-1* components are the X_{k_i} and the last component is X_n

Matrix **A** (*2n-1 x 2n-1*) is a partitioned matrix composed of nine submatrices

$$\mathbf{A} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \mathbf{A}_{13} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \mathbf{A}_{23} \\ \mathbf{A}_{31} & \mathbf{A}_{32} & \mathbf{A}_{33} \end{pmatrix} \qquad (II.17)$$

8 *Let us remember the equilibrium condition (II.6), which implies that* $X_i\, p_{k_i}$ *gives the capital stock at current prices.*

9 *Let us remember that the number of units of productive capacity of sector* k_i *is mesured in terms of* i *equivalents as* $\gamma_i X_{k_i}$.

10 *As with the rate of profit, I take a uniform the wage rate so as not complicate notation. At the static level, the wage rate is linked with the rate of profit by the well-known inverse relationship*

and the submatrices are defined as follows :

$\mathbf{A}_{11}$ and $\mathbf{A}_{12}$ *(n-1 x n-1)* are all zeros;

$\mathbf{A}_{13}$ is the *(n-1)* column vector of the demand coefficients for final commodity *i* (a_{in});

$\mathbf{A}_{21}$ *(n-1 x n-1)* is a diagonal matrix having $(1/T_i)$ on the principal diagonal;

$\mathbf{A}_{22}$ *(n-1 x n-1)* is a diagonal matrix having $[\gamma_i/T_{k_i}]$ on the principal diagonal;

$\mathbf{A}_{23}$ is the *(n-1)* column vector of the demand coefficients for new investments $(a_{k_i n})$;

$\mathbf{A}_{31}$ is the *(n-1)* row vector of labour coefficients for the production of final commodities *i* (a_{ni});

$\mathbf{A}_{32}$ is the *(n-1)* row vector of labour coefficients for the production of capital goods (a_{nk_i});

$\mathbf{A}_{33}$ is a *(1x1)* matrix whose element is zero.

The price system is obtained by introducing some modifications into matrix **A** (formula II.17) and transposing it :

$$\left(\mathbf{A}^{(p)} - \mathbf{I}\right)' \mathbf{p} = \mathbf{0} \qquad \text{(II.18)}$$

where :

p is the column vector *(2n-1)* of prices *(n-1* prices of final commodities and *n-1* prices of capital goods) and the wage rate (the last component).

$\mathbf{A}^{(p)}$corresponds to Matrix **A**, except for submatrices $\mathbf{A}_{21}, \mathbf{A}_{22}, \mathbf{A}_{23}$. Diagonal matrices $\mathbf{A}_{21}$ and $\mathbf{A}_{22}$ now also incorporate the unit profits of sectors, and column vector $\mathbf{A}_{23}$ is modified in order to represent in aggregate the equality between output *per capita* $(\Sigma a_{in}\ p_i + \Sigma a_{k_i n}\ p_{k_i})$ and the sum of wages and profits *per capita* $(w + \Sigma_i\ \pi\ a_{in}\ p_{k_i} + \Sigma_i\ \pi\ \gamma_i\ a_{k_i n}\ p_{k_i})$. Thus,

$\mathbf{A}_{21}$ has $[(1/T_i) + \pi]$ on the principal diagonal,

$\mathbf{A}_{22}$ has $[(\gamma_i/T_{k_i}) + \pi\ \gamma_i]$ on the principal diagonal, and

$\mathbf{A}_{23}$ has $[a_{k_i n} - \pi\ (a_{in} + \gamma_i\ a_{k_i n})]$ $\qquad$ *i = 1,2,...,n-1*

3. *Developments over time*

3.1 In Pasinetti's model technical change takes the usual form of product and process innovations.

Product innovations are dealt with by changing the number of sectors in the system. Thus *n* is variable: it increases when new final commodities are manufactured and it decreases when some products disappear.[11]

Process innovations are dealt with on the (realistic) hypothesis that the most important effect of technical progress is to increase labour productivity. When a new process is adopted, some *inputs* diminish and others increase. However, vertical

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11 *New intermediate commodities do not appear explicitly because they are subsumed by vertical integration.*

integration shows that technical progress exists only when labour coefficients decrease: "technical progress *always* is ultimately labour-saving" (Pasinetti, 1981, p. 212).

Of course, technical change does not spread uniformly over the sectors, but each sector has its own rate of increase of productivity : ρ_i for final sectors and ρ_{k_i} for capital goods sectors ($i = 1,2,...,n-1$), where ρ_{k_i} is the weighted average of the productivity increases of the individual industries producing the (vertically integrated) productive capacity for sector *i* [12].

These sectoral rates of growth of productivity are not constant over time: $\rho_i = f(t)$; $\rho_{k_i} = f(t)$.

If, to simplify notations, we assume that productivity changes are continuous, although different from one sector to another,[13] the development over time of labour coefficients is :

$$a_{ni}(t)=a_{ni}(0)e^{-\rho_i t} \qquad \text{(II.19)}$$

$$a_{nk_i}(t)=a_{nk_i}(0)e^{-\rho_{k_i} t} \qquad \text{(II.20)}$$

Obviously, the fact that the sectoral productivity increases change over time implies that ρ_i and ρ_{k_i} in formulae (II.19) and (II.20) refer to *the average level for the period* (e.g. from the beginning to the fifth period, if $t = 5$), *and not* to the rate of change in each period with respect to the previous one.

3.2. As a result of the increase over time in productivity, real *per capita* incomes grow, and this has a twofold effect on *per capita* consumption: it adds to the size of the basket of consumer goods through the availability of new commodities and modifies the structure of consumption with respect to income, according to Engel's law.

In general terms, this law states that an increase in *per capita* income will not influence uniformly the *per capita* consumption of each good. Figure 1 depicts the typical behaviour of the "Engel curve" for three kinds of commodities : goods that are indispensable for physical reasons (i.e. food) (curve *a*); almost all the other goods (curve *b*); inferior goods (curve *c*).

Of course, given consumer preferences, demand for individual commodities is also determined by the price structure. However, this factor can influence only the

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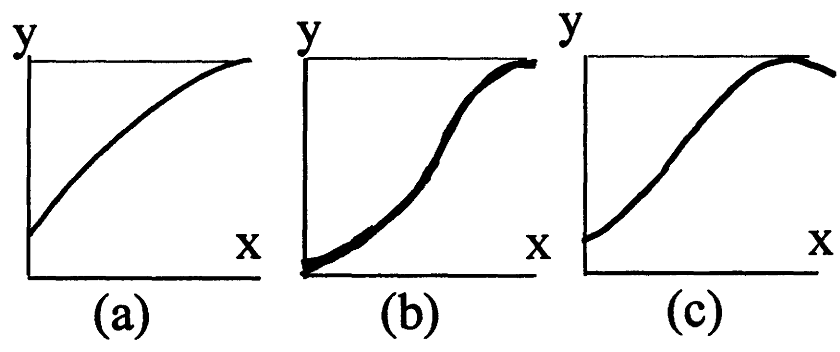
12 *It is useful to state explicitely the links with the input-output analysis. The vertically integrated labour coefficient* $a_{nk_i}(0)$ *is calculated from the input-output matrix at the initial time A(0) by multiplying the vector of direct labour coefficients by the Leontief-inverse matrix (see Pasinetti, 1980 pp. 41-42, footnote 16);* $a_{nk_i}(t)$ *is obtained in the same way on the basis of matrix A(t), which differs profoundly from A(0) because of technical change: new rows and columns are added, some others have disappeared and the coefficients of those industries which remained are changed. Comparing* $a_{nk_i}(t)$ *with* $a_{nk_i}(0)$ *we obtain* ρ_{k_i}, *which thus reflects the complex movement induced by the technical change in question .*

13 *Pasinetti (1981, pp. 83 and 92) uses, instead, an ingenious notation to represent productivity increases as segments of straight lines.*

Fig. 1

Examples of Engel curves



x = real income per capita

y = expenditure

slope of the Engel curve, without changing its basic shape. "In the long run, it is the level of real income - not the price structure - that becomes the relevant crucial variable" (Pasinetti, 1981, p. 73).

For final commodities we write:

$$a_{in}(t) = a_{in}(0)\, e^{r_i t} \qquad i = 1,2,\ldots,n\text{-}1 \qquad \text{(II.21)}$$

The demand for new investment follows the same path :

$$a_{k_i n}(t) = a_{k_i n}(0)\, e^{r_i t} \qquad \text{(II.22)}$$

Since the rate of change of demand is not constant over time ($r_i = f(t)$), r_i in formulae (II.21) and (II.22) is *an average* for the period (as in the case for ρ), and *not* simply the annual rate of change.

3.3 *Population* is assumed to grow at a constant rate *g*, given exogenously. Then,

$$X_n(t) = X_n(0) e^{gt} \qquad \text{(II.23)}$$

4. *Some results*

4.1. The dynamic expression for *prices* is obtained by taking into consideration technical change. For this purpose, let us insert formulae (II.19) and (II.20) into the price equations (II.14) and (II.15) and take the wage rate as *numéraire*, assuming that it stays at a fixed level $(\bar{w})$ over the entire period: $(w(t) = \bar{w})$, for any *t*. We obtain :

$$p_i(t) = IC5_i\, e^{-\rho_i t} + (\pi + \frac{1}{T_i})\, C2_i\, IC4_i\, e^{-\rho_{k_i} t} \qquad \text{(II.24)}$$

$$p_{k_i}(t) = C2_i\, IC4_i\, e^{-\rho_{k_i} t} \qquad \text{(II.25)}$$

where the initial conditions $IC4_i$ and $IC5_i$ are respectively :

$$IC4_i = a_{nk_i}(0)\, \bar{w}$$

$$IC5_i = a_{ni}(0)\, \bar{w}$$ [14]

and constant $C2_i$ is defined as above.

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14 *Constant IC4i represents the wage incorporated into one unit of commodity k_i at the beginning of the period (t = 0).*
Constant $IC5_i$ *has the same meaning but refers to the direct labour needed to produce commodity i.*
On the other hand, the term $IC4_i\, e^{-\rho_{k_i} t}$ *in formula (II.25) refers to the wage incorporated in one unit of commodity k_i at period t. The same applies to the term* $IC5_i\, e^{-\rho_i t}$ *in formula (II.24), with reference to the direct labour for commodity i.*

We thus see that the relative price of any commodity falls at a varying rate equal to that at which labour productivity increases in the corresponding vertically integrated sector. This rate of change is the weighted average of two productivity growth rates: that relating to the production of the commodity concerned (sector *i*) and that relating to the production of the corresponding capital goods (sector k_i).

A convenient way of studying the price movements is to measure them with respect to a general level of prices that, by construction, remain stable over time. This is obtained taking as reference Pasinetti's *dynamic standard commodity*, a composite commodity for which productivity is growing at the weighted average rate of the economic system (Pasinetti, 1981, p. 101 *et seq.*). Let us indicate by ρ^* this "standard" rate of growth of productivity and close the price system with the function :

$$w(t) = \bar{w}.e^{\rho^* t} \qquad \text{(II.26)}$$

where $\bar{w}$ = w (0).

The price equations (II.24) and (II.25) then become :

$$p_i(t) = IC5_i \; e^{(\rho^* - \rho_i)t} + (\pi + \frac{1}{T_i}) \, C2_i \; IC4_i \; e^{(\rho^* - \rho_{k_i})t} \qquad \text{(II.27)}$$

$$p_{k_i}(t) = C2_i \;\; IC4 \, e^{(\rho^* - \rho_{k_i})t} \qquad \text{(II.28)}$$

It follows that, in terms of the dynamic standard commodity, "half of the prices, on (a weighted) average, will increase, and the other half, on (a weighted) average will decrease, so that the general level of prices neither increases nor decreases" (Pasinetti, 1981, p. 105). More precisely, the price of the commodities produced with above-average productivity growth will decrease and the opposite for the commodities with below-average productivity growth.[15]

4.2. Assuming that the system tends to follow a dynamic equilibrium path, i.e. there is full employment and the equilibrium condition for capital accumulation is fulfilled (see Appendix I; Pasinetti, 1981, Chapter III. 2), the change over time in physical output is :

Final commodities

$$X_i(t) = IC3_i \, e^{(g+r_i)t} \qquad (i = 1,2,...,n-1) \qquad \text{(II.29)}$$

where $IC3_i$ stands for the initial conditions (i.e. demand at t = 0):

$$IC3_i = a_{in}(0) X_n(0)$$

We see that the growth of output depends on the growth of demand. This rate of growth comprises two elements:

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15 *The link between wage increases and the growth of the dynamic standard commodity is thus an equilibrium condition to avoid inflation. See Pasinetti(1981, pp. 161-164 and 1993, pp. 77-80) for the discussion of the consequences of the non-fulfillment of such a condition*

• a general term *g* (the growth of population), which influences in a uniform way the demand for all commodities;
• a specific element r_i : the growth of demand for final commodity *i*. The factors determining r_i will be investigated later.

Capital goods

$$X_{k_i}(t) = \left(g + \dot{r}_i + \frac{1}{T_i} \right) D3_i \;\; IC3_i \;\; e^{(g+r_i)t} \qquad \text{(II.30)}$$

where :

$IC3_i$ refers to the initial conditions as above;

$D3_i$ is: $D3_i = \frac{T_{k_i}}{T_{k_i} - \gamma_i - (r_i + g)\gamma_i T_{k_i}}$;

$\dot{r}_i$ is the (instantaneous) percentage rate of change of demand relative to the previous period;

r_i is the average rate of growth of demand from the beginning to period *t*.

The first two terms on the right in formula (II.30) [$(g + \dot{r}_i + 1/T_i)\ D3_i$] are in the nature of an *accelerator*, in that they establish a proportionality link between the output of final commodities and the output of the corresponding capital goods sector. We shall see later, when dealing with long-waves, that this generates a cyclical movement in X_{k_i}.

4.3 Employment can be studied at two levels (sectoral and aggregate) in order to work out the macroeconomic condition for full employment.

(a) At sectoral level, employment ($E_i(t)$) is obtained by multiplying the output of the sector (X_i or X_{k_i}) by the quantity of labour per unit of output (the technical coefficients a_{ni} or a_{nk_i}) :

$$E_i(t) = a_{ni}(t) X_i(t)$$
$$E_{k_i}(t) = a_{nk_i}(t) X_{k_i}(t)$$

Substituting X_i and X_{k_i} by their dynamic values (formulae (II.29) and (II.30)), we obtain :

$$E_i(t) = IC1_i \, e^{(g + r_i - \rho_i)t} \qquad \text{(II.31)}$$

$$E_{k_i}(t) = D3_i \left(g + \dot{r}_i + \frac{1}{T_i} \right) IC2_i \;\; e^{(g + r_i - \rho_{k_i})t} \qquad \text{(II.32)}$$

where $IC1_i$ and $IC2_i$ stand for the initial employment conditions :

$$IC1_i = a_{ni}(0) \; a_{in}(0) \; X_n(0)$$
$$IC2_i = a_{nk_i}(0) \; a_{in}(0) \; X_n(0)$$

We recognize in formula (II.32) the accelerator term.

Formulae (II.31) and (II.32) are very interesting because they make it possible to establish a balance between the factors determining the level of employment in each sector. There is, first of all, the direct negative effect of technical change due to the increase in productivity. However, this damaging effect can be offset by the increase in demand for the commodities produced by the sector, which depends in turn on two elements : (i) a general one (the rate of growth of population), which spreads uniformly over all sectors, and (ii) a specific factor (r_i) relating to the increase in demand for the commodity produced in the sector.

Since, in Western societies, population is roughly stationary (g=0), the crucial element is the strength of technical change with respect to the growth of demand. When $r_i > \rho_i$, the sector will expand and create new jobs. When $r_i < \rho_i$, the sector will decline and destroy jobs.

Technical change influences demand in two ways : via the decrease in price of the commodity involved in technological change and through an income effect, if real wages follow the dynamic of productivity.

However, demand tends to become saturated (Engel's law), with the result that the flow of technical change creates a tendency towards technological unemployment. This tendency can be overcome by increasing the number of commodities offered in the market. This corresponds to the historical trend in industrialized countries, where product innovations have more than offset the depressing effect on employment exerted by technical change. Pasinetti's model takes this fact into account because it is "open" : the number of sectors changes to reflect the appearance of new products and the disappearance of some old activities.

(b) The macroeconomic condition for full employment is derived from system (II.16). This is a homogeneous system which admits a non-trivial solution if the determinant of matrix (**A** - **I**) is equal to zero. Calculating such a determinant, we obtain :

$$\Sigma_i a_{ni} a_{in} + \Sigma_i C1_i a_{nk_i} a_{k_i n} + \Sigma_i C1_i (1/T_i) a_{nk_i} a_{in} = 1 \qquad \text{(II.33)}$$

Until now, it was assumed that total population equals total labour force. If we drop this equality and indicate by :

μ the proportion of active to total population, and

ν the proportion of total time to working time,

formula (II.33) becomes :

$$\Sigma_i a_{ni} a_{in} + \Sigma_i C1_i a_{nk_i} a_{k_i n} + \Sigma_i C1_i (1/T_i) a_{nk_i} a_{in} = \mu \nu \qquad \text{(II.34)}$$

The left handside of equation (II.34) refers to the sum of three types of demand for labour force :

- for *per capita* consumption of final commodities : $\Sigma_i a_{ni} a_{in}$
- for net investments *per capita* : $\Sigma_i C1_i a_{nk_i} a_{k_i n}$
- for the replacements of capital goods used up in sectors *i* and k_i : $\Sigma C1_i (1/T_i) a_{nk_i} a_{in}$

In fact, a_{in} is a consumption coefficient while a_{ni} is a labour coefficient; their product gives the quantity of labour required to produce the *per capita* consumption of commodity *i*; summing the labour requirements for all *i*, we obtain the proportion of total labour employed in the consumption sector. Similar observations can be carried

ECONOMIC PAPERS n. 109:

Radical innovations and long waves into Pasinetti's model of structural change: output and employment

<u>Corrigendum</u>

- *cover page:* add the following:

The author is very much indebted to K. Knottenbauer for her comments on a previous version of this paper and for drawing attention to some oversights.

- *page 19*: Footnote 12 is to be replaced by the following:

12 *It is useful to state explicitly the links with the input-output analysis. The vertically integrated labour coefficient* $a_{nk_i}(0)$ *is calculated from the input-output matrix at the initial time A(0) on the basis of a rather complex formula, in which appear the vector of direct labour coefficients and the Leontief-inverse matrix (see Pasinetti, 1980 p. 26);* $a_{nk_i}(t)$ *is obtained in the same way from matrix A(t), which differs profoundly from A(0) because of technical change: new rows and columns are added, some others disappear and the coefficients of those industries which remain are changed. Coefficient* $a_{nk_i}(t)$ *thus incorporates the complex movement induced by all types of technical change (embodied and disembodied) which materialized in the time span considered. This movement find a synthetic expression in* ρ_{k_i}, *which results from the comparison of* $a_{nk_i}(t)$ *and* $a_{nk_i}(0)$.

- *page 30:* σ is to be replaced by ρ_{tr}

- *page 35:* Formula (IV.2): σ is to be replaced by ρ_{tr}

- *page 36:* Formula (IV.3) and the following text: σ is to be replaced by ρ_{tr}

- *page 44*: Delete footnote 31

- *page 53:* Formula (IV.24) should be:

$$E_i(t) = ICl_i \; e^{(r_i^{(iw)} - \rho_i^{(iw)})\, t}$$

out for the other two terms in equation (II.34).

Full employment is reached only if the sum all these sectoral demands for labour uses up the available labour force.

Formula (II.34) can be rewritten in a dynamic form, taking into consideration the changes over time in demand and population as well as the equilibrium condition for capital accumulation (see Appendix I). We obtain :

$$(1/\mu\nu)\Sigma_i a_{ni}(0)\, a_{in}(0) e^{(r_i-\rho_i)t} + (1/\mu\nu)\Sigma_i Cl_i \left[Dl_i (r+g) + \frac{1}{T_i} \right] a_{in}(0) a_{k_i n}(0) e^{(r_i-\rho_{k_i})t} = 1 \qquad \text{(II.35)}$$

where $D1_i = \dfrac{\gamma_i T_{k_i} + T_i (T_{k_i} - \gamma_i)}{T_i (T_{k_i} - \gamma_i - (r_i + g)\gamma_i T_{k_i})}$

In a capitalist economy with no regulatory authority for the labour market, there is no guarantee that condition (II.35) will be fulfilled automatically because the learning processes in production and consumption operate indipendently: when technical and structural changes are deep-seated, the most likely outcome is unemployment. Full employment can thus be attained only through an active economic policy.

Let us conclude this chapter by defining the notions of "natural" rate of profit and "natural" rate of interest.

5. At the logical stage of the "natural" system the rate of profit and the rate of interest have different meanings to their meanings in capitalist society.

In the "natural" system investments are financed by profits, and the "natural" *rate of profit* (π_i^*) has the function of assuring that the macro-economic equilibrium condition for investment is fulfilled, i.e. equality between total savings and total investment. π_i^* is defined as what is required for the accumulation of capital in a growing economy. For each final commodity *i* we have:

$$\pi_i^* = g + r_i \qquad (i = 1,2, ...,n-1) \qquad \text{(II.36)}$$

where g and r_i have been defined above.

Since r_i is not uniform, each sector *i* has a "natural" rate of profit which differs from the rate of profit in other sectors.

If "natural" prices prevail, and therefore include a "natural" rate of profit, each sector will receive an amount of profits exactly equal to the amount of its equilibrium investments: enterprises consequently do not need to borrow or lend (Pasinetti 1981, p. 171)[16].

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16 *The "natural" rate of profit has nothing to do with the "productivity of capital" but it is determined by "growth, and the increasing productivity of* labour*" (Pasinetti 1981, p. 133). The rate of change of demand depends, in fact, on labour productivity (see paragraph 3.2 above). This point will be developed in part IV of the present paper*

Whilst the "natural" rate of profit belongs to the productive sphere, the "natural" *rate of interest* pertains to the consumption sphere.

On this point Pasinetti makes the simplifyng assumption that all final commodities are perishable: to have full employment, what can be produced in one period by the available productive capacity should be consumed in the same period, otherwise it is lost for ever. This means that, apart from what is required for investments, in aggregate there are no other savings.

At the individual level, however, the situation is different because some persons can decide not to consume all their income (and save) while others want to spend more (and dissave). Inter-personal lending and borrowing, excluded in the production sphere, now become possible. This necessitates the emergence of financial assets and liabilities, representing claims on future consumption by some individuals against others[17].

The "natural" rate of interest (i^*) is that rate which preserves intact through time the purchasing power of all loans. In this context, the choice of *numéraire* is crucial because, for the same (actual) rate of interest, there is a whole set of own-rates of interest for each commodity taken as *numéraire* (see Pasinetti 1981, pp. 158-161 and 1993, pp. 86-91 for a thorough discussion). When purchasing power is defined in terms of labour, the "natural" rate of interest in nominal terms (i^*) is equal to the rate of growth of the wage rate (σ_W), whatever the *numéraire*:[18]

$$i^* = \sigma_W \tag{II.37}$$

It is clear from above that, in the "natural" system, the rate of interest is conceptually very different from the rate of profit. In capitalist economies, however, things appear different because the institutional set-up distorts relations operating at the fundamental level. In fact, financial markets are open to both individuals and firms: lending and borrowing among individuals are not separated from lending and borrowing among enterprises and all financial transactions occur in the same financial market. This creates the well known tendency for the real interest rate and the general rate of profit to equalise (Pasinetti, 1981, p. 175).

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17 *Obviously, overall positive and negative claims (financial assets and liabilities) cancel each other out*

18 *For a complete analysis of this topic, which is only touched here, see Pasinetti (1993, pp. 89-91 and 1981, pp. 160 ff.)*

III. TECHNOLOGICAL REVOLUTIONS AND OTHER HYPOTHESES[19]

1. To incorporate technological revolutions into Pasinetti's model, let us first recall the features of the general cycle. As noted by Schumpeter, each long wave develops in four phases: (a) prosperity, when growth is high; (b) recession, when growth decelerates; (c) depression, when growth is near zero or even negative; (d) recovery, when growth is modest. Prosperity and recession represent the long expansion while depression and recovery represent the long stagnation (Van Dujn, 1983). In this paper I conventionally assume that a long-wave lasts for 50 years, long expansion and stagnation for 25 years each, and the individual phases for : 20 years (prosperity), 5 years (recession), 15 years (depression) and 10 years (recovery).

2. Van Duijn (1983) shows that, during the depression phase of the long-wave, the major innovations tend to appear in existing industries and concern processes as well as products. During the recovery, the number of major process innovations in existing industries falls sharply, while the flow of product innovations continues. However, the dominant feature of this phase is the appearance of radical product innovations leading to the creation of new industries. The propensity to innovate, therefore, seems to change as described in Table 1 (Van Duijn, 1983, p. 137).

In this section I consider only *process* innovations, not because product innovations are not important but simply because there is no *a priori* indication of the pattern of productivity changes in these new industries (or new activities). This second type of innovations is dealt with at the end of Section IV.

3. I assume that the sectoral and aggregate changes in labour productivity result from two developments, the second being clearly the more important :

(a) an underlying slow increase (e.g. 0.5-1% per annum) common to all sectors and due to incremental innovations (embodied technical change[20]), organizational improvements and learning by doing/using (disembodied technical change);

(b) the progressive adoption of radical process innovations (technological revolution) which materialize in a large and sudden increase in the level of productivity (e.g. a jump of 30-50% with respect to the previous level). This kind of technical change is always embodied in capital goods.

This process is illustrated in Figure 2, with reference to individual innovators; the *x* axis represents the productivity index (volume of output per unit of labour) and the *y* axis time. The line α_{tr} depicts the general trend and lines AA'T, ABB'T and ACC'T the productivity level of the first, second and third innovator. Consider the third innovator: Figure 2 shows that in periods 1 and 2 he operates with the old technology, obtaining a modest increase in productivity (1% per annum in this example); in period 3 he adopts the new technology and achieves a massive increase in productivity (30%); from period 4 onwards, there are only minor changes

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19 *In this section, I follow, with minor changes, Reati and Raganelli (1993, pp. 9-14).*

20 *E.g. new "generations" of machinery*

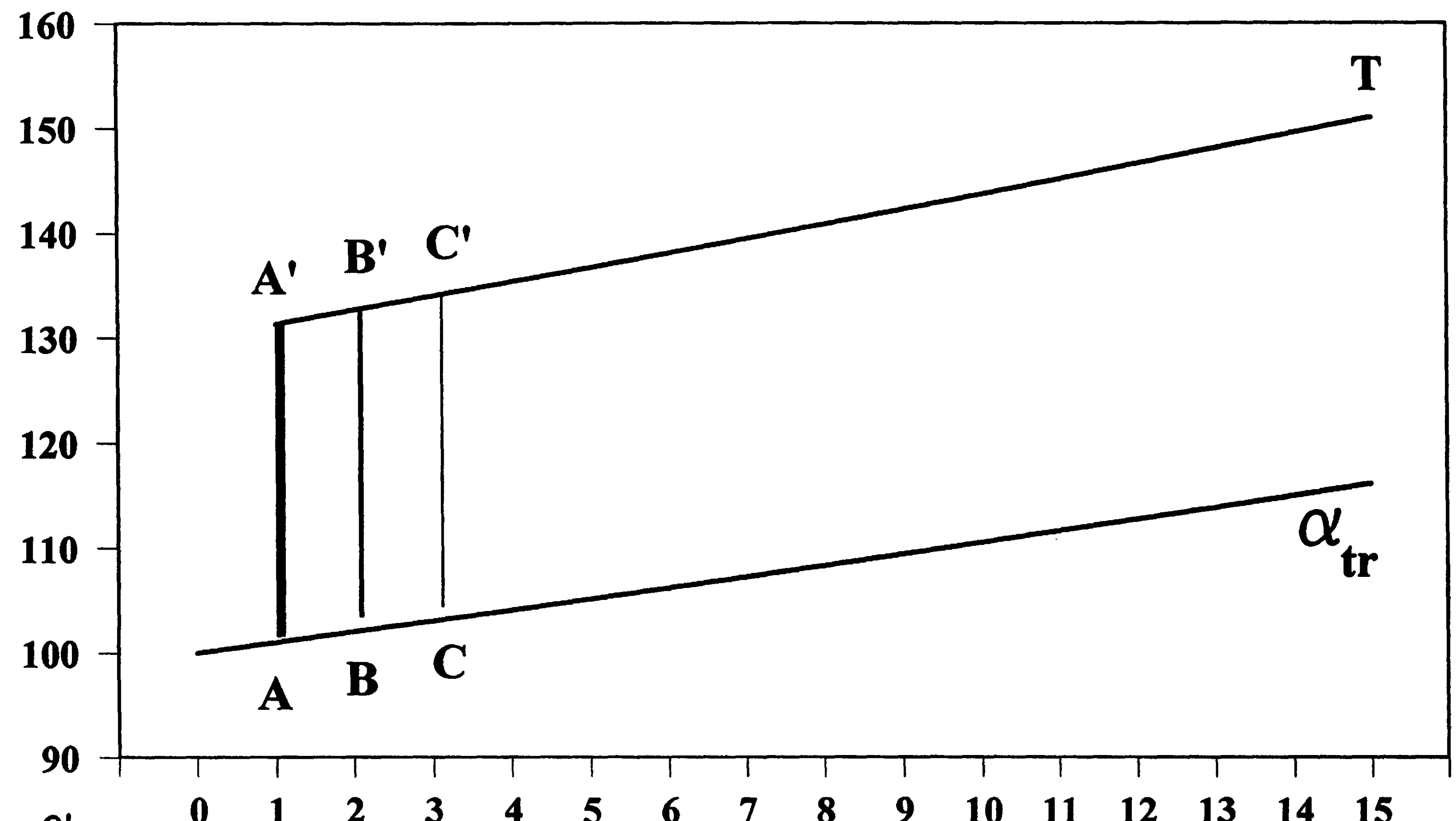
Table 1 : Propensity to innovate during the phases of the long-wave
(Van Duijn, 1983, p. 137)

	STAGNATION		EXPANSION	
	Depression	**Recovery**	**Prosperity**	**Recession**
1. Process innovations (existing industries)	***	*	**	**
2. Product innovations (existing industries)	***	***	*	*
3. Product innovations (new industries)	*	****	**	*
4. Process innovations (basic sectors)	*	**	***	**

The more stars, the greater the propensity to innovate.

Fig. 2

Productivity level of the innovators (indices)



A α_{tr} and A' T seem linear simply because the exponential growth rate is small (1% per annum) in the new technical bases (incremental innovations), with a small improvment in productivity (1% per annum).

The general formula of the functions depicted in Figure 2 is simple. If

$\alpha_{ji}(t)$ represents the productivity level at time *t* for one innovator *j* belonging to sector *i*. Alternatively, *j* could also relate to a group of innovators acting simultaneously; in other words, *j* shows in this case the share of total output of *i* which is concerned by the technological revolution.[21]

t_o, t_i and T the beginning of the period (set at zero), the moment in which the firm adopts the innovation, and the end of the period

σ the common trend of productivity (annual rate of change) resulting from incremental innovations

Δ_i the percentage leap in productivity due to the radical innovation,

our function is :

$$\alpha_{ji}(t) = \alpha_{ji}^{(1)}(t);\ \alpha_{ji}^{(2)}(t) \qquad \text{(III.1)}$$

where:

$\alpha_{ji}^{(1)}(t)$ is the first segment, for $t_0 \leq t \leq t_i$ (before enterprise *j* adopts the radically new technology)

$\alpha_{ji}^{(1)} = \alpha_{ji}(0).e^{\sigma(t-t_0)}$

$\alpha_{ji}^{(2)}(t)$ is the upper segment, for $t_i \leq t \leq T$, i.e. after the radical innovation, when the firm benefits simply from incremental innovations

$\alpha_{ji}^{(2)}(t) = C\,(1+\Delta_i)\ e^{\sigma(t-t_i)}$,

C is the productivity level immediately prior to the radical innovation

$C = \alpha_{ji}(0).e^{\sigma(t_i-t_0)}$

4. Turning now to the process of *diffusion* within a sector, I make two assumptions regarding the duration of the diffusion process and the shape it takes.

(a) On the first point, I assume that the diffusion is complete by the end of the phase of the long-wave in which the technological revolution started. If, for instance, a radical innovation is introduced in sector *i* at the beginning of the depression, on the basis of my conventional schedule it will be only at the end of the 15th year that all the output is obtained with the new technology; if the first innovation appears at the beginning of the recovery, it will take 10 years to become generalized, and so on. Note, however, that this hypothesis is not essential (and at the end of Section IV of the paper, it is dropped). It is adopted here for the sake of convenience in order to identify the mechanism governing prices and quantities when technological change takes the form of technological revolution; for this purpose, the length of the diffusion period is instrumental and can thus be taken arbitrarily.

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21 *From now, the term "innovator" will have this second meaning of a* ***group of enterprises*** *operating at the same time; j will refer to the same definition.*

(b) As regards the pattern of diffusion, my basic assumption is that the introduction of radical process innovations in a sector follows an asymptotic growth path.

(b.1) To formalize this process, I adopt here a sigmoid function (S-shaped) : namely, a logistic or a Gompertz-type curve as in Figure 3a and 3b. Their analytical expressions are :

Logistic function

$$D(t)=\frac{K}{1+a\,e^{-b(t-t_c)}} \qquad \text{(III.2)}$$

where:

D(t) is the cumulative share of the total production of the sector affected by the technological revolution at period t,

K is the asymptote of the function (the saturation level); in Figure 3a, K = 100,

a and b are constants; *a* determines the position of the curve with respect to the time axis and *b* gives the slope of the curve. In Figure 3a : a = 1 and b = 0.7, and

t_c is the mid-point of the period. Since the diffusion is supposed to be complete in 15 years' time, t_c = 7.5.

Gompertz function

$$D(t)=K\,a^{b^t} \qquad \text{(III.3)}$$

where:

D(t) and K are defined as above, and

a and b are constants. Constant *a* determines the value of the function when t = 0 and *b* determines the slope of the curve. In Fig 3b : a = 0.001 and b = 0.6.

The logistic function is symmetrical, which means that at the mid-point in the diffusion period half of the output of the sector is generated with the new technology $[D(t_c)=50]$. Its derivative function is "bell-shaped" and its instantaneous rate of growth is constantly decreasing.

The logistic is derived from an "epidemic" model in which the diffusion of a phenomenon is proportional to the number of cases in which the phenomenon in question has already appeared (Van Duijn, 1983, pp. 32-34; Stoneman, 1983, pp. 69-70). In the case of the diffusion of a new technology, the "epidemic" model means that the adoption of this technology at time *t* (the increase in D(t)) is proportional to the amount of information existing at that time on the advantages and characteristics of such technology.

The Gompertz function is not symmetrical, but it too displays an instantaneous rate of growth that is constantly decreasing. It can be used to describe the diffusion process when we have reason to think that the "take-off" of the new technology is very rapid.

It should also be noted that the diffusion process can refer to the adoption of successive "generations" of the same innovation.

(b.2) The economic justification for a sigmoid pattern of diffusion is empirical.[22]

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22 *See Van Duijn (1983, Chapter II) for a survey of the literature.*

Fig. 3 a: Examples of diffusion functions
a) Logistic curve (a = 1; b = 0.7)

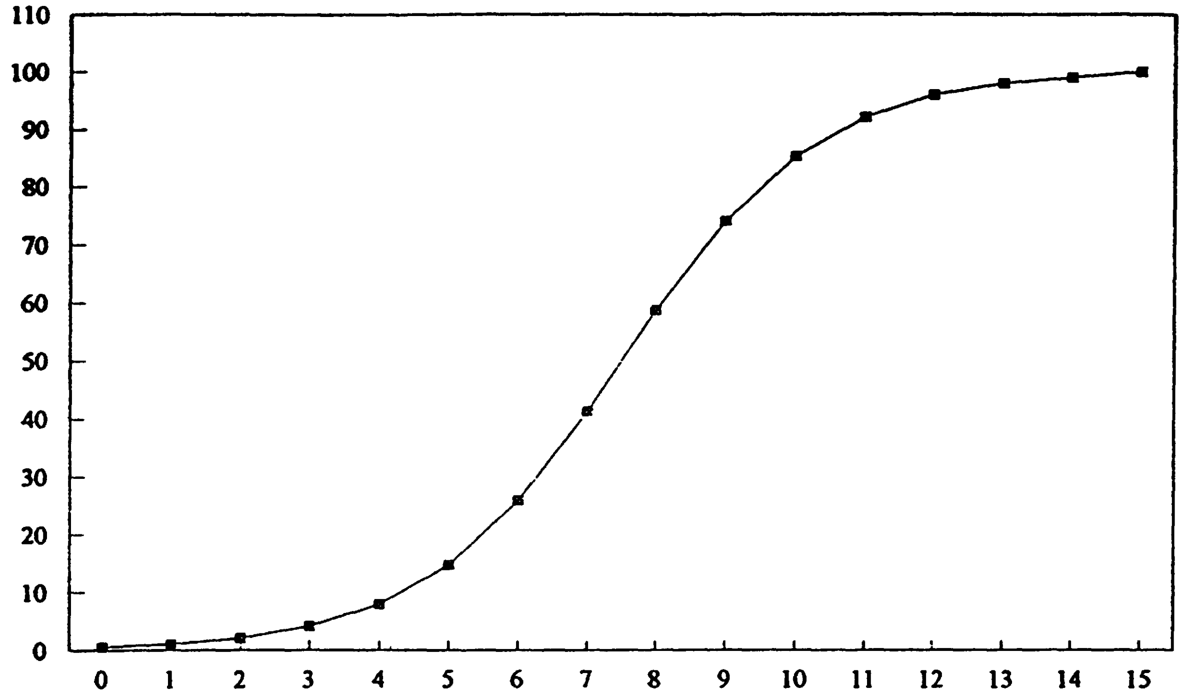
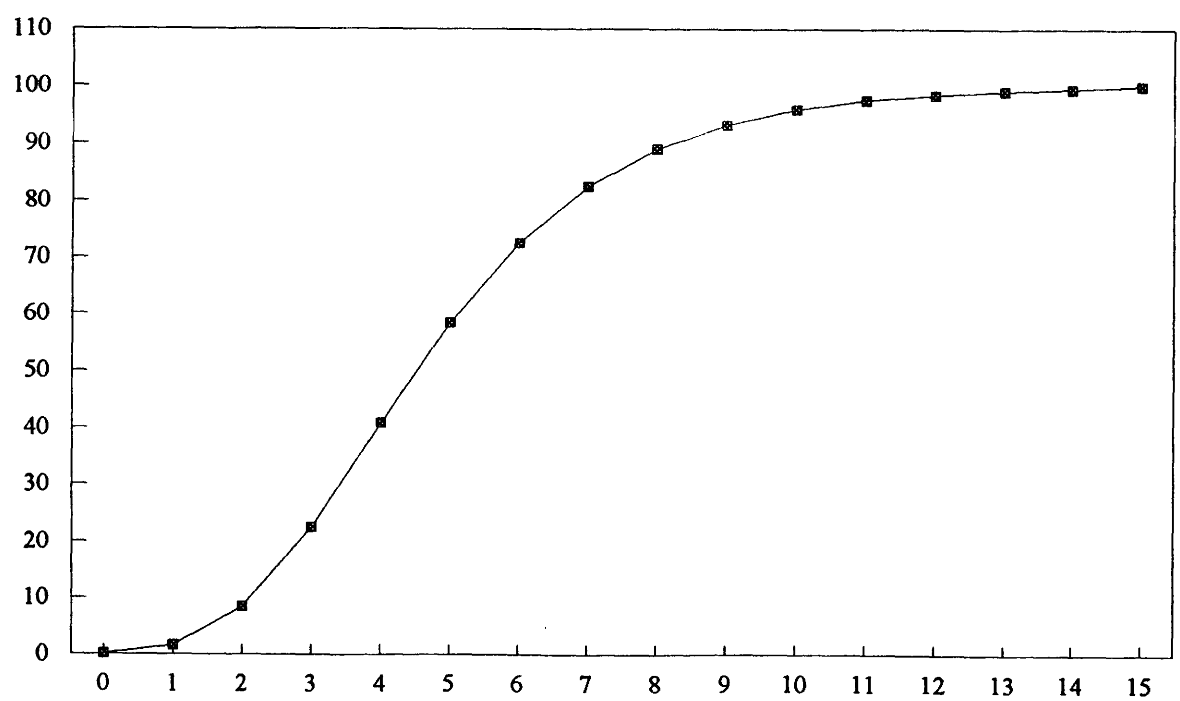


Fig. 3 b: Examples of diffusion functions
a) Gompertz curve (a = 0.001; b = 0.6)



For instance, the enterprises in the sector do not have the necessary information to perceive immediately the advantage of imitating the first innovator or, if they are fully aware of the new opportunities, they prefer to wait so as to avoid the cost of an accelerated scrapping, or they are unable to adopt the new technology for organizational or institutional reasons (they do not know how to master the new technology or do not have the necessary skills; managers are reluctant to change radically the organization of the company).

5. Two methodological problems should be addressed. The first refers to the conceptual level of the analysis, the second to the equilibrium conditions on which Pasinetti's model is based. Some indications are then given concerning the numerical simulations which will be presented later.

(a) On the first point, my analysis will be carried out within the logical framework of the natural system, conceived as a *methodological device* to avoid unnecessary complications at this stage of the enquiry. This means that the changes in prices, quantities and employment that will emerge are the movements which are technically possible when there is a technological revolution. What will actually appear on the market depends on the strategies of enterprises and on the influence of institutions, which are, however, constrained by what happens at the level of the natural system.

(b) The economic relations in Pasinetti's model are based on the hypothesis that the system is in equilibrium. This implies that there is no idle or insufficient productive capacity at sectoral level[23] and that there is full employment of the labour force at macroeconomic level.

In a long-wave context such conditions are not satisfied : the long stagnation is, for instance, characterized by massive unemployment and considerable spare capacity in many sectors. However, the analysis that follows does not necessarily require such stringent conditions for equilibrium.

In fact, for the sectoral part of my enquiry, a disequilibrium situation might have two implications: (i) the sector concerned by the technological revolution could not find the appropriate productive capacity; (ii) the output level which is technically possible is not attained because of insufficient demand. Nevertheless, these possibilities do not necessarily have to be considered in the sense that, at least *for the sectors examined*, it can be reasonably posited that such obstacles are not operating. This is what is done in the present paper.

This difficulty reappears at the end of my investigation, when I outline the overall dynamic of the system. Since there is now a steadily growing number of sectors concerned by the technological revolution, it becomes difficult to avoid bottlenecks or insufficient demand. However, if we remember that my analysis is situated at the logical level of the "natural" system, the difficulty disappears here too because my purpose is not to reconstruct the whole long-wave movement but merely to show how the inter-sectoral diffusion of the technological revolution produces a long-wave pattern for output. Sectoral bottlenecks or insufficient demand could give

23 *Actually, this condition is embodied in the equation for the output of the capital goods sector (see appendix I: the equilibrium conditions)*

a bias to or delay the impetus coming from the technological revolution but, as we shall see later, there is no inconsistency between my results for the basic forces underlying any industrial system and the conditions for the appearance of a long upswing.

(c) Numerical simulations are frequently carried out to make the mathematical results more evident. In one case (changes in total employment), this is the only way to reach definite conclusions.

Except where otherwise stated, for these numerical simulations I took, for the productivity functions, a logistic diffusion curve in which K = 1 (or 100, according to the circumstances), a = 1 and b = 0.7 (as in Figure 3a) and a productivity shock of 30% (Δ_i = 0.3).[24] For coefficients T_i, T_{k_i} and γ_i, I gave the following plausible values: T_i = 12; T_{k_i} = 10; γ_i = 2; the rate of profit was set at 20% (π = 0.2).

It could be argued that no general conclusions can be drawn from such numerical simulations because the results depend on the specific values assigned to the parameters. This objection is not really important because I am concerned with the *direction* of the long-term trends, and not with the precise magnitudes of the variables. Several tests on the sensitivity of the final outcome to the values assigned to T_i, T_{k_i} and γ_i have shown that, when coefficients T_i, and T_{k_i} change, this does not alter substantially the final result. For γ_i things are different because this coefficient has quite a strong influence on the final result. However, as I shall explain later, even in the most crucial case of employment, alternative values for γ_i do not affect the general conclusion regarding the long-term trend.

24 *Clearly, when the scope of the technological revolution is wider (a larger productivity shock), the results that I obtain for prices, quantities and employment are magnified, and vice versa when the productivity shock is less than the 30% assumed here.*

IV. RESULTS

1. The main part of this section is devoted to the study of changes in output and employment at *sectoral level*, the aim being to provide a basis for an understanding of the overall dynamic of the system.

I shall begin with a three-stage analysis of process innovations. First, I determine the sectoral productivity changes stemming from the technological revolution. This result will be useful as regards the dynamic development of prices, already examined in Reati and Raganelli (1993). Second, I derive the pattern of demand resulting from the mechanism set into motion by the technological revolution. Third, I use these results to obtain the physical quantities and employment, in a similar manner as in formulae (II.29) to (II.32).

Product innovations will be treated at a later stage, it being assumed that the demand for such commodities evolves according to the product life-cycle pattern. Note, however, that in practice these two kinds of radical innovations occur simultaneously. What characterizes the technological revolutions is their pervasiveness; eventually the radical process innovations will also be adopted for producing the (completely) new products and, in this way, the price and demand of these commodities will track the path resulting from the analysis of process innovations.

Finally, an attempt will be made to construct the overall dynamics of the system by taking into consideration the progressive diffusion of the technological revolution to a growing number of sectors in the economy.

Since my purpose is to study the basic mechanisms of the model, I focus, for the sake of convenience, on the depression phase of the long-wave, i.e. the period during which innovation is more intense (see Table 1 above).

(a) Sectoral analysis: process innovations

(a.1) <u>*General aspects*</u>

2. The productivity level of any sector *i* (α_i) or k_i is obtained by combining the technological revolution function as given by formula (III.1) with a diffusion function (D(t)). At time *t* we have :

$$\alpha_i(t) = \alpha_{ji}(t).D(t) + \alpha_{zi}(t).[1 - D(t)] \qquad \text{(IV.1)}$$

where *j* refers to the last innovators and *z* represents the other enterprises.

If we consider formula (III.1) more explicitly, formula (IV.1) becomes :

$$\alpha_i(t) = \alpha_i(0)\,[(1 - D(t)) + (1+\Delta_i)D(t)]e^{\sigma(t-t_o)}$$

$$\alpha_i(t) = \alpha_i(0)\,[1+\Delta_i D(t)]\,e^{\sigma(t-t_o)} \qquad \text{(IV.2)}$$

The result of formula (IV.2) is worth noting: it shows, in fact, that changes in the productivity of any sector *i* are strongly influenced by the pattern of diffusion of the technological revolution. Since the leap in productivity (Δ_i) is multiplied by the diffusion function, the greater the intensity of the technological revolution (quantified by the magnitude of Δ_i), the more sectoral changes in productivity will reflect the shape of the diffusion function.

In Figures 4a and 4b, I present alternative examples of technological revolutions in sector k_i operating with two different diffusion functions : a logistic (Figure 4a, line D_1) and a Gompertz curve (Figure 4b, line D_2). The productivity function of the innovators is that of formula (III.1) and Figure 2 with three shocks: 70% (line Δ_i = 0.7), 30% (line Δ_i = 0.3) and 10% (line Δ_i = 0.1). Appendix II provides a numerical exemple for the case in which the productivity shock is 30%.

If the technological revolution follows a diffusion pattern which differs from k_i to *i*, the diffusion function of the vertically integrated sector will be the weighted average of the diffusion curves of the individual sectors *i* and k_i and the resulting productivity curve will reproduce the shape of the diffusion function. I illustrate this in Figure 5, drawn up on the basis of a logistic for *i* and a Gompertz curve for k_i (as in Figure 3b), with weightings of 0.4 and 0.6 respectively, and a productivity shock of 30% in both sectors.

If, contrary to what I have assumed so far, the diffusion process is shorter than the phase of the long-wave in which the technological revolution started, the productivity of the sector follows the diffusion pattern for the time required for the diffusion to be completed and then tracks the trend. This is shown in Figure 6, in which diffusion takes 9 years and the productivity shock is 30%.

The instantaneous rate of growth of the productivity function is obtained simply by calculating the derivative of formula (IV.2) with respect to time and then dividing it by the function itself (the logarithmic derivative). If we denote the first derivative by the sign ' (as in *f'*) we have :

$$\frac{d\alpha_i(t)}{dt} = \alpha_i(0)\ [\Delta_i\ D'(t)]\ e^{\sigma t} + \alpha_i(0)\ [1+\Delta_i\ D(t)]\ \sigma.e^{\sigma t}$$

$$= \alpha_i(0).e^{\sigma t}[\Delta_i\ D'(t) + \sigma(1+\Delta_i\ D(t))]$$

The percentage rate of growth is :

$$\frac{\alpha_i'(t)}{\alpha_i(t)} = \sigma + \frac{\Delta_i\ D'(t)}{1+\Delta_i\ D(t)} = \dot{\rho}_i^{(iw)} \qquad \text{(IV.3)}^{25}$$

For formula (IV.3), we can make the same observations as for formula (IV.2): apart from the small influence of the trend rate of growth (σ, which empirically would amount to 0.5-1% per annum), the main determinants of the instantaneous rate of increase in productivity are the intensity of the technological revolution (Δ_i) and the shape of the diffusion function (D(t)). As Figure 7a shows, when D(t) is a logistic the rate of change fluctuates in a "bell-shaped" manner; when the diffusion function is a Gompertz curve, the "bell" is skewed, as in Figure 7b. Below, this pattern of change

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25 *To be precise, the rate of growth of productivity should be written:* $\dot{\rho}_i^{(iw)}(t)$. *The time index is omitted to simplify the notation.*

Fig. 4 a: Diffusion function and labour productivity in sector k_i according to different strength of the technological revolution

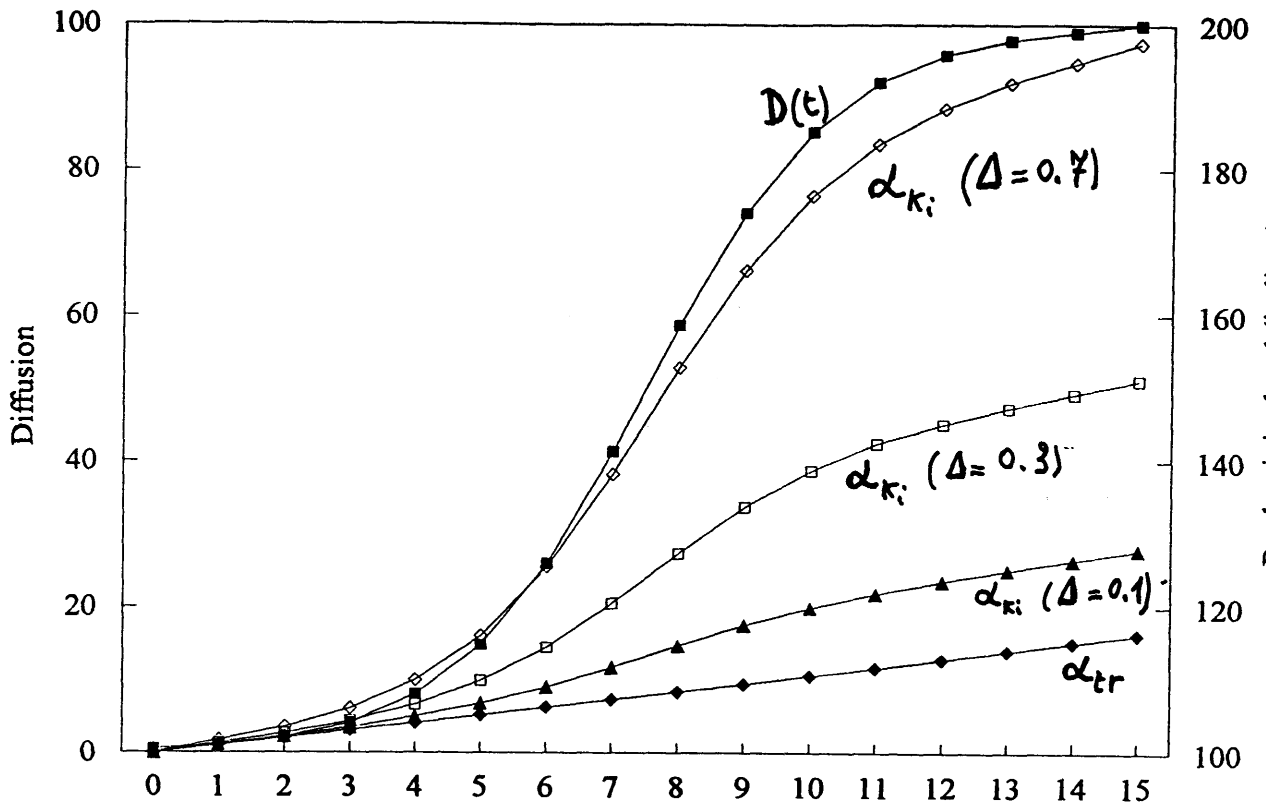


Fig. 4 b: Diffusion function and labour productivity in sector k_i according to different strength of the technological revolution

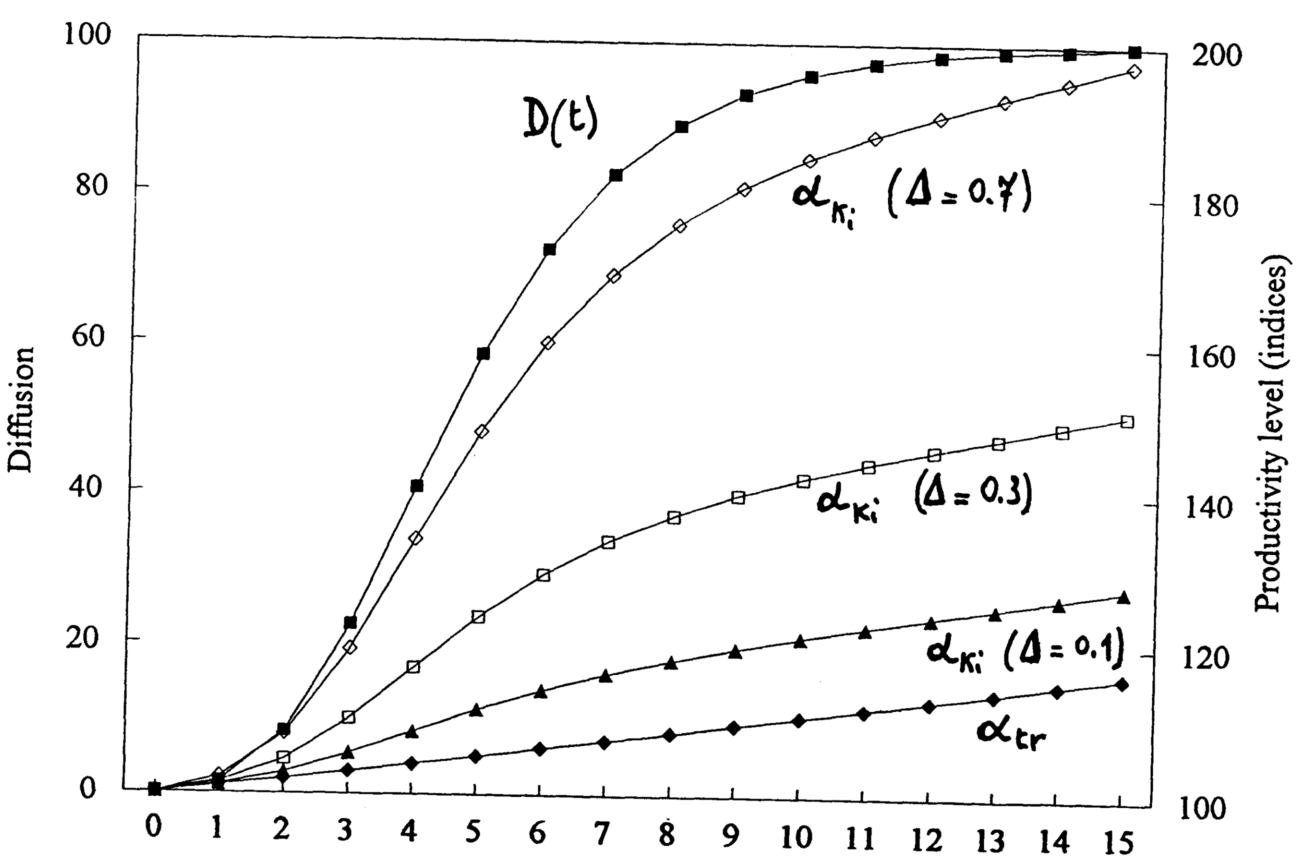


Fig. 5: Productivity level in the vertically integrated sector *i* when *i* and k_i have a different diffusion function

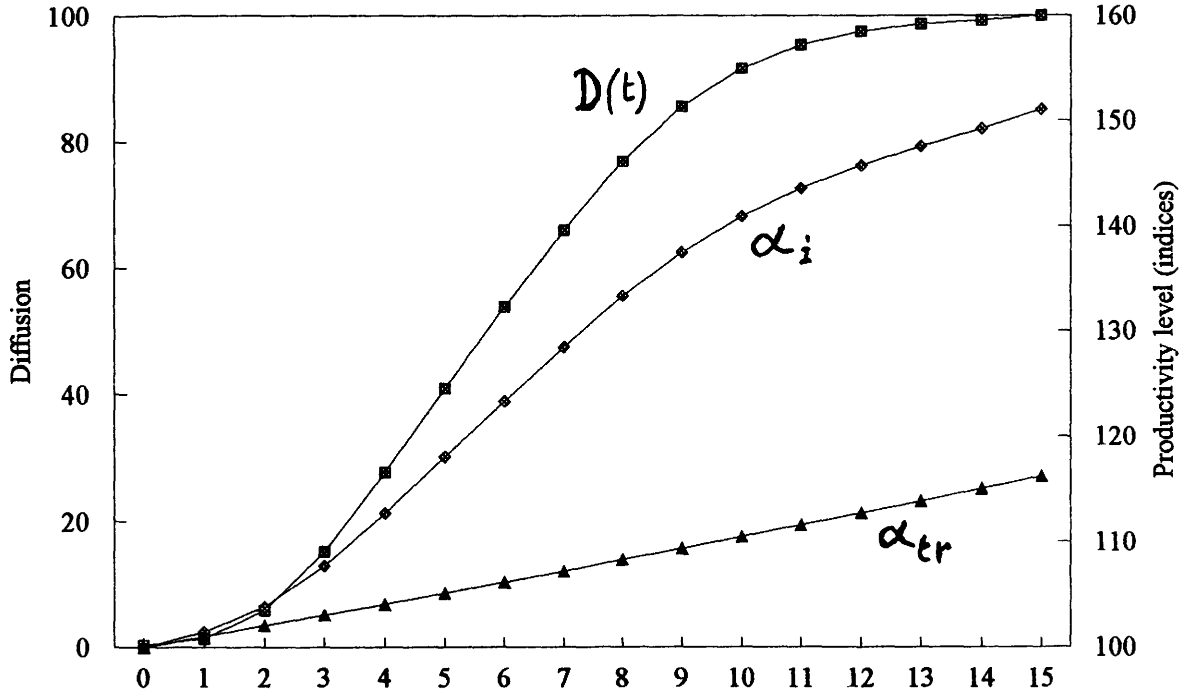


Fig 6: Productivity of the sector (α_i) when the diffusion is shorter

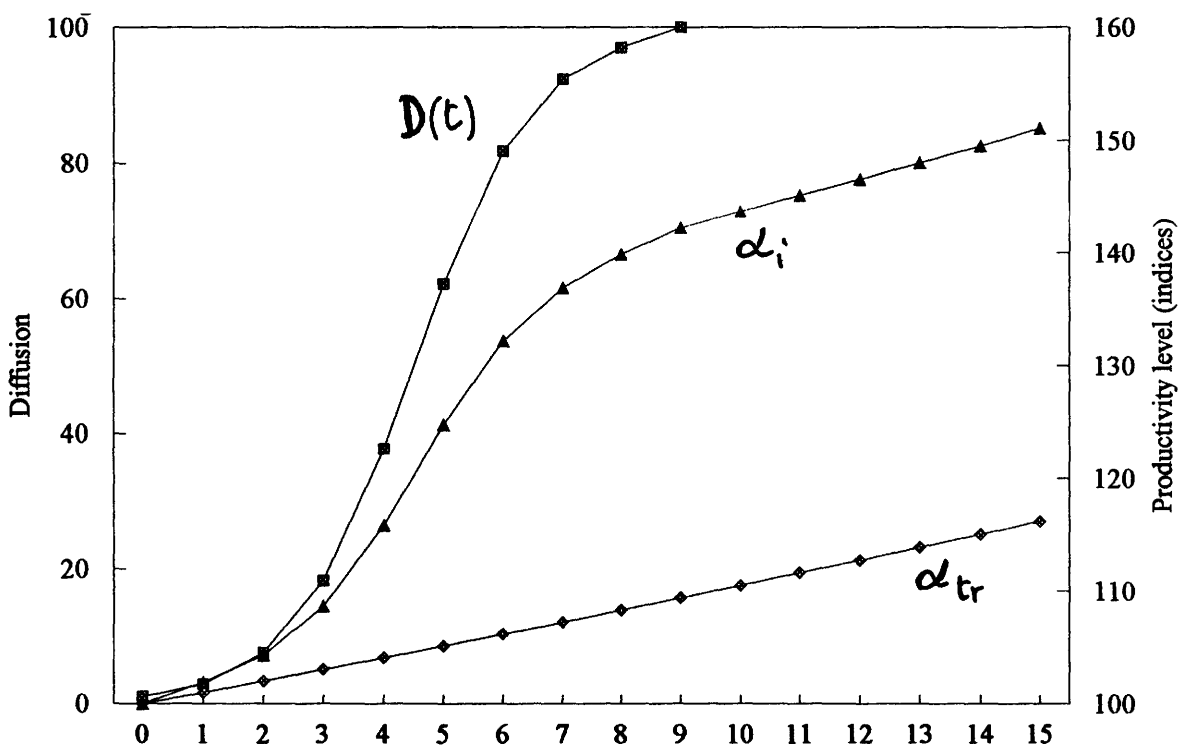


Fig. 7 a: Instantaneous rate of change of the productivity function
logistic diffusion pattern

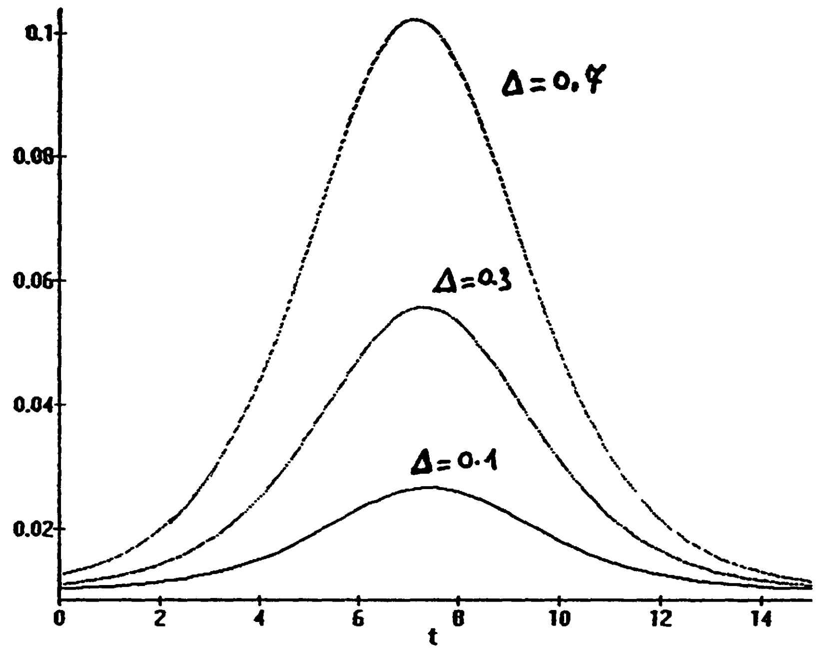
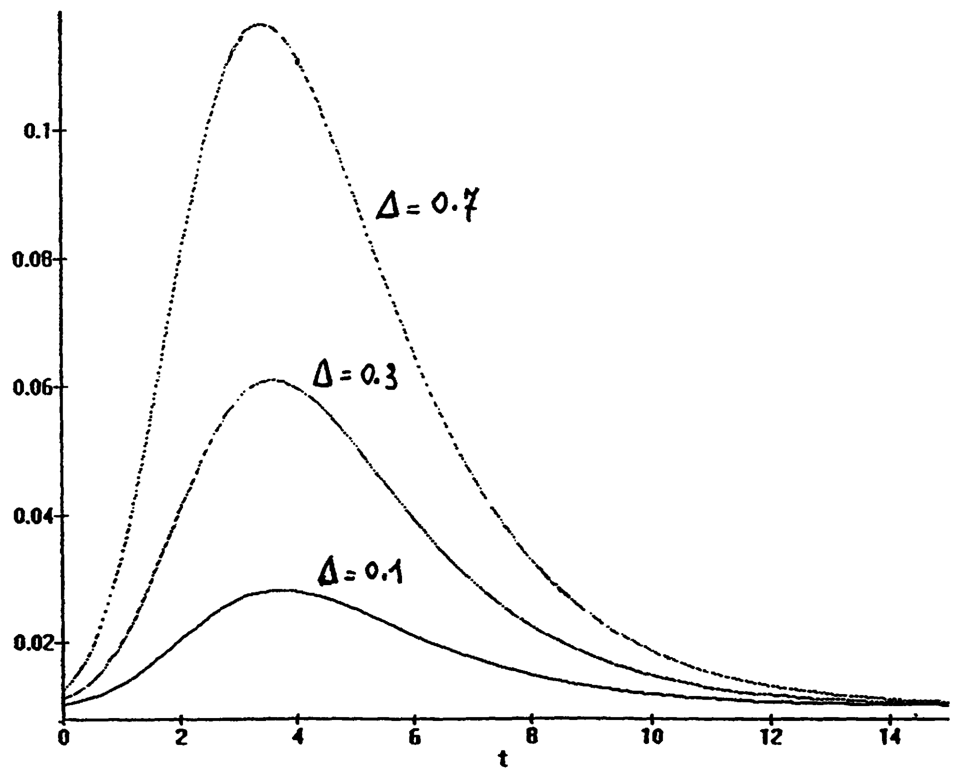


Fig. 7 b: Instantaneous rate of change of the productivity function
Gompertz diffusion pattern



will be associated with the notion of *long-waves* (simply because a "bell-shaped" rate of change of a function generates an S-shaped curve, which is the typical long-wave movement).

Changes in productivity have a twofold effect: a direct influence on the price of the commodity produced with the new technology and an indirect effect on the rate of growth of the demand for that commodity.

(*a.2*) *Prices and profits*

3. To prepare the ground for the analysis that follows, I shall discuss here the analytical expression of the percentage change in prices. However, before working out these results, I would first recall the main results of the Reati and Raganelli (1993) paper on the link between prices and productivity in the long-wave context and extend this preliminary part to a digression on the dynamics of the rate of profit.

(a) *Long-waves in productivity and prices*

Relying on the strong assumption that coefficients T and γ as well as the rate of profit remain constant[26] (in order to isolate the effects of technological revolution), Reati and Raganelli (1993) show that Pasinetti's general finding (formulae (II.14) and (II.15)) also holds when there are long waves: the long-term price movements are strongly shaped by the features of the diffusion function. Figure 8 provides an example concerning sector k_i.

What is found in the case of p_{k_i} applies to p_i *mutatis mutandis*: the price curve has a corresponding inverted profile with respect to the combined productivity functions of sectors *i* and k_i.

(b) *The rate of profit of the innovators*

The influence of the diffusion pattern is really pervasive. It is, for instance, what emerges from an investigation of the dynamic of profitability of each innovator.[27] [28] For this purpose, let us consider sector k_i and distingush three different rates of profit:

i) the "natural" rate of profit of the sector ($\pi^*_{k_i}$), resulting from the fact that p_{k_i} steadely decreases in accordance with the changes in productivity of the sector;

ii) the "Schumpeterian" profit rate of the innovators (π_{j,k_i}); and

iii) the rate of profit of the other firms (that could even be a "Schumpeterian"

26 *This is, obviously, an unrealistic hypothesis : as a matter of fact, the rate of profit shows a clear long-wave pattern, with fluctuations ranging sometimes from 1 to 10. For a theoretical discussion and empirical evidence see Reati (1990).*

27 *I follow here Reati and Raganelli (1993, pp. 18-19)*

28 *The reader should remember what is said above on the fact that the word "innovator" does not necessarily refer to just one enterprise but to the one or more firms covering a fraction j of the total output of the sector*

rate of losses), which realize only the trend productivity growth.

In figure 9 I compare these three profit rates using the numerical parameters of figure 4.a (case $\Delta = 0.3$) and assuming that:

- the cost functions of the enterprises are the same, *i.e.* the innovators benefit from the same sudden decrease in unit cost while, for the other enterprises, the cost reduction is determined by the productivity trend;

- the rate of profit of the sector ($\pi^*_{k_i}$) is set at a sufficiently high level (30% in this case) to allow the late innovators to stay in business in spite of the fact that their individual rate of profit is temporarily much lower.

We observe the following mechanism: in period *1*, the technological revolution entails a sharp cut in the innovator's unit cost; since the price decreases only slightly (in accordance with the productivity growth of the sector), there is a corresponding jump in the profit rate of the innovator (from *a* to *a'* , i.e. from 30% to 68.5% in this example); since $\pi^*_{k_i}$ remains stable because of the synchronised evolution of price and productivity, all other firms experience a small reduction in their profit rate (from *a* to *b*, i.e. from 30% to 29.6%); this encourage some of them to imitate the first innovator. In period *2* this process replicates, driven by the action of the second innovator: its profit rate jumps from *b* to *b'*, while that of the other firms declines from *b* to *c*. The evolution over the total period is characterised by a steady decline of the profit rates of the successive innovators (line *a',b',c',....,*$\pi^*_{k_i}$) until they converge to the sectoral level. A similar decline, operating below $\pi^*_{k_i}$, appears for the profitability of the firms that have not yet adopted the radical innovation (line *b,c,d,...,q*). Both the evolution of the successive innovators and that of the remaining firms reflect the inverted shape of the diffusion function.

(c) *The percentage rate of change of prices*

(c.1) Let us start with the *capital goods* sector, taking the "dynamic standard commodity" as *numéraire* (formula II.15) and writing the "standard" rate of growth of productivity (ρ^*). For this purpose, I assume that the technological revolution occurs in only one branch of the capital goods sector (which is generically designed by k_i), while in all the other branches (i.e. the remaining *n-2* capital goods branches, indicated by k_j, and the *n-1* final commodities branches) there are only incremental innovations[29] and the rate of increase in productivity is thus ρ_{tr}. This means that *changes* in the "standard" rate of productivity growth are not a *direct* function of time: in fact, ρ^* varies only because the individual branch of the capital goods sector under consideration has productivity growth higher than all the other branches ($\rho_{k_i} > \rho_{tr}$); without this influence, ρ^* would have been constant (and equal to ρ_{tr}):

29 *The reader should remember footnote 12, precising that* ρ_{k_i} *is always a derived magnitude, calculated from the input-output matrices relative to the period in question. As such,* ρ_{k_i} *is a shorthand expression for the whole set of changes in the individual industries forming the vertically integrated sector* k_i.

Fig. 8: Productivity and price in sector k_i
(indices)

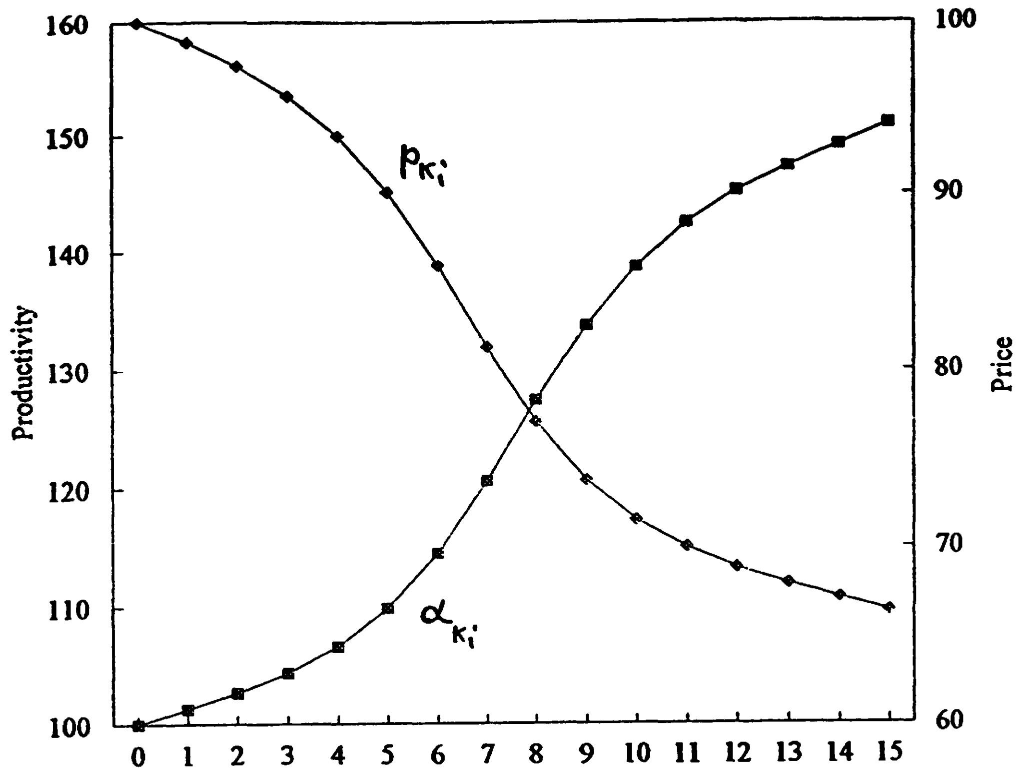
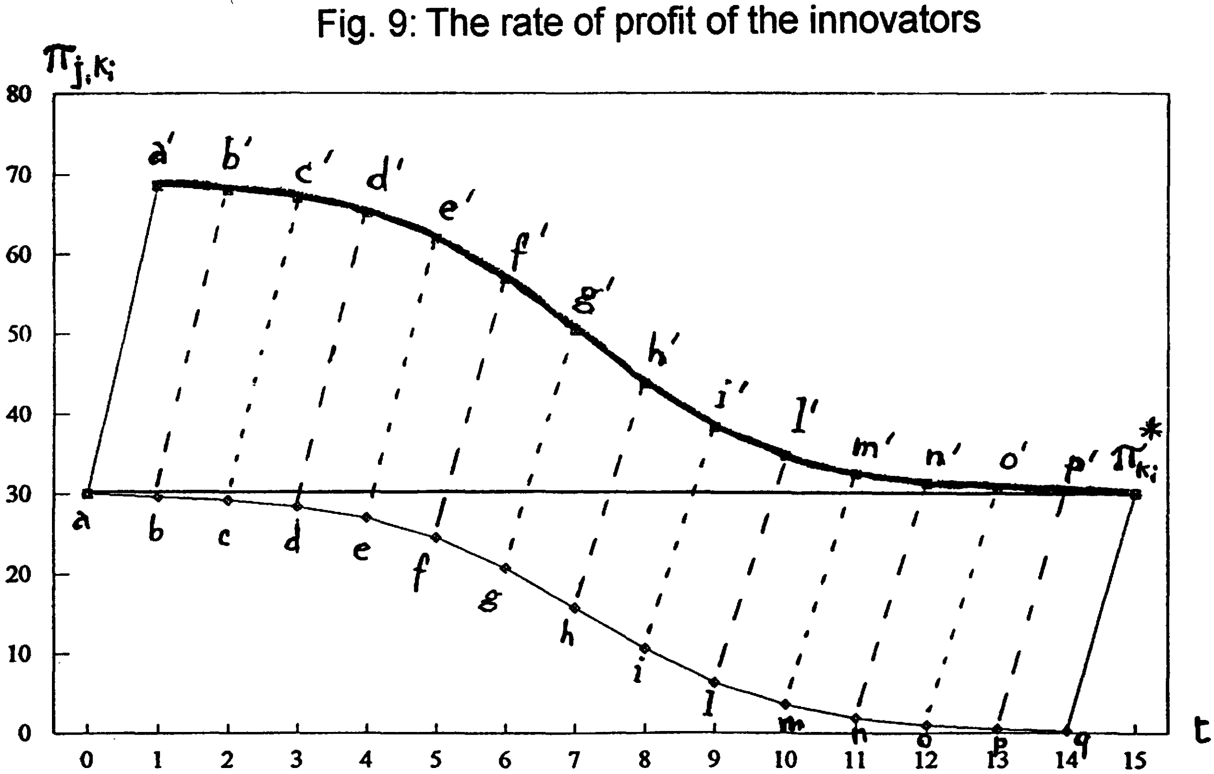


Fig. 9: The rate of profit of the innovators



$$\rho^*(t)=f(\rho_{k_i}(t));\quad \rho_{k_i}=g(t),\ \text{and}\ \frac{\partial\rho^*}{\partial\rho_i}=0;\quad \frac{\partial\rho^*}{\partial\rho_{k_j}}=0$$

The "standard" rate of productivity growth varies as follows:

$$\frac{d\rho^*}{dt}=\frac{\partial\rho^*}{\partial\rho_{k_i}}\cdot\frac{d\rho_{k_i}}{dt}=\rho_{k_i}^{*'}\ \rho'_{ki}=F^*_{ki} \qquad \text{(IV.4)}$$

In practice, the size of F^*_{ki} depends on the relative importance of sector k_i: if its share of total employment is not large (e.g. less than 10%), F^*_{ki} will be very small.

Taking account of formula (IV.4), the percentage rate of change of prices is obtained by calculating the logarithmic derivative of formula (II.28) with respect to time:

$$\frac{dp_{k_i}}{dt}=C2_i\ IC4_i\left[(F^*_{ki}-\rho'_{k_i})t+\rho^*-\rho_{k_i}\right]e^{(\rho^*-\rho_{k_i}).t}$$

$$\frac{p'_{k_i}}{p_{k_i}}=-(\rho_{k_i}+\rho'_{k_i}\ t)+\rho^*+F^*_{ki}\ t \qquad \text{(IV.5)}$$

As already noted, ρ_{ki} refers to the average level for the time span considered, and it is the same for ρ*. The term $\left(\rho_{k_i}+\rho'_{k_i}\ t\right)$ is a particular way of denoting the (instantaneous) percentage rate of change of ρ_{k_i} with respect to the preceding period;[30] $\left(\rho^*+F^*_{ki}\ t\right)$ has the same meaning but refers to the *standard* rate of growth of productivity. For the purposes of my analysis, it is better to express formula (IV.5) in a more direct manner, stressing the fact that in sector k_i there is the technological revolution:

$$\frac{p'_{k_i}}{p_{k_i}}=-\dot{\rho}^{(iw)}_{k_i}+\dot{\rho}^* \qquad \text{(IV.6)}$$

where $\dot{\rho}^{(iw)}_{k_i}$ and $\dot{\rho}^*$ are the percentage rates of change at period *t* with respect to *t-1*.

In practice, formula (IV.6) poses some problems because it requires the computation of $\dot{\rho}^*$. This is avoided taking as the *numéraire* any commodity *h* unaffected by the technological revolution, and whose productivity increases at the trend rate $(\rho_{tr}=\rho_h)$. We are, of course, deprived of the advantage of the stability of the general price level: in terms of the new *numéraire,* the decrease in p_{k_i} will be stronger and the wage increases weaker $\left(\rho_h<\rho^*\right)$. However, in so far as the

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30 *This is a general result. In fact, for any magnitude A developing exponentially* $A(t)=A(0)\,e^{b\,t}$, *the instantaneous (percentage) rate of change with respect to the previous period is :*

$$\frac{dA(t)/dt}{A(t)}=b+b't$$

technological revolution affects only a small part of the economy (just one sector k_i in the present case), the difference between ρ_h and $\overset{\bullet}{\rho}{}^*$ is small, and the former gives a good approximation of the latter.

Equation (IV.6) is then rewritten substituting $\overset{\bullet}{\rho}{}^*$ with ρ_{tr}

$$\frac{p'_{k_i}}{p_{k_i}} = -\overset{\bullet}{\rho}{}_{k_i}^{(iw)} + \rho_{tr} \qquad \text{(IV.7)}$$

(c.2). The position with regard to *final commodities* is slightly more complicated because p_i can change for three alternative reasons:

- because the technological revolution appears only in the final commodities sector i concerned. Thus, in the other n-2 final sectors j as well as in the capital goods sectors k_j there are only incremental innovations;[31]
- because there is a technological revolution only in sector k_i;
- because the technological revolution occurs in both sectors i and k_i.

Let us deal with each of these cases separately.

(c.2.1) Technological revolution only in sector i

This means, in particular, that: $\frac{d\rho_{k_i}}{dt} = 0$; $\frac{\partial \rho^*}{\partial \rho_{k_i}} = 0$,

and formula (IV.4) becomes:

$$\frac{d\rho^*}{dt} = \frac{\partial \rho^*}{\partial \rho_i}\frac{d\rho_i}{dt} = \rho_i^{*'}\,\rho_i' = F_i^* \qquad \text{(IV.8)}$$

Proceeding as before, we have, from formula (II.27) (*numéraire*: the "dynamic standard commodity"):

$$\frac{dp_i}{dt} = IC5_i\left[\left(F_i^* - \rho_i'\right)t + \rho^* - \rho_i\right]e^{(\rho^*-\rho_i)t} + C3_i\ C2_i\ IC4_i\left[F_i^*\,t + \rho^* - \rho_{k_i}\right]e^{(\rho^*-\rho_{k_i})t}$$

where $C3_i = \pi + (1/T_i)$

If we recall the meaning of constants $IC4_i$ and $IC5_i$ given in paragraph II.2.4 above (see formula (II.24) and footnote 12), the derivative of p_i can be written in a more compact way by defining the following *final* conditions:

$$FC4_i = IC4_i\ e^{(\rho^* - \rho_{k_i})\,t}$$

$$FC5_i = IC5_i\ e^{(\rho^* - \rho_i)\,t}$$

$$\frac{dp_i}{dt} = \left[-\left(\rho_i + \rho_i'\,t\right) + \rho^* + F_i^*\,t\right]FC5_i + \left[-\rho_{k_i} + \rho^* + F_i^*\,t\right]C3_i\ \ C2_i\ \ FC4_i$$

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31 *This can be interpreted in two ways. It could mean, for instance, that sector k_i produces the new plant and equipment for i on the basis of a traditional technique. Alternatively, sector k_i is a new sector with the most advanced techniques, somtething which does not imply further jumps in productivity.*

Dividing this derivative by p_i (formula (II.27), into which $FC4_i$ and $FC5_i$ were inserted), the (instantaneous) rate of change of the price of final commodity *i* with respect to the preceding period is:

$$\frac{p_i'}{p_i} = \omega_1 \left[-\left(\rho_i + \rho_i' t\right) + \rho^* + F_i^{*'} t \right] + \omega_2 \left[-\rho_{k_i} + \rho^* + F_i^{*'} t \right] \qquad \text{(IV.9)}$$

where:

$$\omega_1 = \frac{FC5_i}{FC5_i + C3_i \ C2_i \ FC4_i} \qquad \text{(IV.10)}^{32}$$

$$\omega_2 = \frac{C3_i \ C2_i \ FC4_i}{FC5_i + C3_i \ C2_i \ FC4_i} \qquad \text{(IV.11)}$$

As with the capital goods sector, in practice ρ^* is small and F_i^* very small; ρ_{k_i} is also small since there are assumed to be no radical innovations in this sector. Thus, the main factor determining the magnitude of the percentage decrease in the price of final commodity is the productivity growth of the sector itself, weighted by ω_1.

As we can see from the above definition, the weightings ω_1 and ω_2 have a clear economic meaning. Let us consider, for this purpose, the denominator of ω_1 and ω_2, which is a synthetic expression for $p_i(t)$ (formula (II.27)): FC5i is the direct wage incorporated into commodity *i* at period t, while [C3i . C2i . FC4i] is the indirect wage (i.e. the wage incorporated into the capital goods for one unit of *i*) and the profit component of p_i, expressed in terms of wages. Thus ω_1 is the share of direct wages for *i* with respect to price, while ω_2 is the share of indirect wages and profits.

Expressing , as before, formula (IV.9) in terms of rates of change with respect to the preceding period ($\dot{\rho}_i^{(iw)} = \rho_i + \rho_i' t$; $\dot{\rho}^*_{(i)} = \rho^* + F_i^{*'} t$) and considering that $\omega_1 + \omega_2 = 1$ as well as that, in this case, $\rho_{k_i} = \rho_{tr}$, we finally obtain:

$$\frac{p'_i}{p_i} = -\dot{\rho}_i^{(iw)} \omega_1 - \rho_{tr} \varpi_2 + \dot{\rho}^*_{(i)} \qquad \text{(IV.12)}$$

If we change *numéraire* and, as before, take a commodity *h* unaffected by radical technical change, the previous result becomes:

$$\frac{p'_i}{p_i} = (-\dot{\rho}_i^{(iw)} + \rho_{tr})\, \omega_1 \qquad \text{(IV.13)}$$

This shows even more clearly way that, when the technological revolution affects only one final sector, the changes in its prices are fundamentally driven by productivity growth in the sector itself. The graph of function (IV.13) is thus an inverted bell.

Coefficient ω_1, which reduces the size of productivity changes in the above formula ($0<\omega_1<1$), calls for comment. Looking at its definition (formula IV.10), we see, first of all, that ω_1 is declining over time (because it is a function of ρ_i); and,

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32 *Since the magnitude of ω_1 and ω_2 changes over time, they should be written : $\omega_1(t)$ and $\omega_2(t)$. The time index is omitted to simplify the notation.*

since sector *i* is affected by the technological revolution ($\rho_i^{(iw)}$ is bell-shaped), ω_1 will appear as an inverted logistic. The size of ω_1 depends on the degree of mechanization of the sector: if mechanization is high, i.e. the relative importance of direct labour is low, ω_1 will be small and its variability large. This implies that the decline in prices made possible by productivity growth will be drastically reduced. The converse holds true when sector *i* has a low degree of mechanization: ω_1 will be high and its changes over time relatively modest.[33]

(c.2.2) Technological revolution only in sector k_i

This implies that: $\rho_i = \rho_{tr}$; $\quad \dfrac{d\rho_i}{dt} = 0 \quad$ and $\quad \dfrac{\partial \rho^*}{\partial \rho_i} = 0$

$$\frac{d\rho^*}{dt} = \frac{\partial \rho^*}{\partial \rho_{k_i}} \frac{d\rho_{k_i}}{dt} = \rho_{k_i}^{*'} \rho_{k_i}^{'} = F_{ki}^*$$

Since the algebraic derivation of the percentage rate of price changes is the same as in Section (b.1) above *mutatis mutandis*, I will simply give the result:

"dynamic standard commodity" as numéraire

$$p_i' / p_i = -\dot{\rho}_{k_i}^{(iw)} \omega_2 - \rho_{tr}\, \omega_1 + \dot{\rho}_{(ki)}^{*} \qquad \text{(IV.14)}$$

any commodity h as numéraire

$$p_i' / p_i = (-\dot{\rho}_{k_i}^{(iw)} + \rho_{tr})\, \omega_2 \qquad \text{(IV.15)}$$

(c.2.3) Technological revolution in both sectors

I shall be very brief on this point too. My basic assumption implies:

$$\frac{d\rho^*}{dt} = \frac{\partial \rho^*}{\partial \rho_i} \frac{d\rho_i}{dt} + \frac{\partial \rho^*}{\partial \rho_{k_i}} \frac{d\rho_{ki}}{dt} = F_{iki}^*$$

Omitting the mathematical passages for the sake of brevity, the percentage rate of price changes is:

"dynamic standard commodity" as numéraire

$$p_i' / p_i = -\dot{\rho}_i^{(iw)} \omega_1 - \dot{\rho}_{k_i}^{(iw)} \omega_2 + \dot{\rho}_{(ik_i)}^{*} \qquad \text{(IV.16)}$$

To simplify, we could suppose that the strength and diffusion of the

33 *A numerical simulation with $\rho^* = 0.01$ and $\rho_i^{(iw)}$ taken from Fig. 7a ($\Delta_i = 0.3$) shows that, if IC5i is 20% of the total price at t = 0, $\omega_1 = 0.199$ at t = 1 and $\omega_1 = 0.162$ at t = 15; the percentage change is -19%.*
If IC5i is 80% of the total price at t = 0, with all the other parameters unchanged, $\omega_1 = 0.80$ at t = 1 and $\omega_1 = 0.76$, at t = 15; the percentage change over the period is now -6%.

technological revolution is the same in both sectors, i.e. $\rho_i^{(iw)} = \rho_{k_i}^{(iw)} = \rho^{(iw)}$. Formula (IV.16) thus becomes:

$$p_i' / p_i = -\dot{\rho}^{(iw)} + \dot{\rho}^{*}_{(ik_i)} \qquad \text{(IV.17)}$$

Since no confusion can arise, the notation for the"standard" rate of productivity growth will be simplified by omitting the subscript which indicates the sector(s) in which the technological revolution occurs.

any commodity h as numéraire

$$p_i' / p_i = -\dot{\rho}_i^{(iw)} \omega_1 - \dot{\rho}_{k_i}^{(iw)} \omega_2 + \rho_{tr} \qquad \text{(IV.18)}$$

This result can be expressed more simply, as in formula (IV.17):

$$p_i' / p_i = -\dot{\rho}^{(iw)} + \rho_{tr} \qquad \text{(IV.19)}$$

Let us now consider the second effect of productivity growth, that on demand, and address first the case in which the technological revolution occurs in final sectors only.

(a.3) <u>Physical quantities and employment</u>

(a.3.1) Technological revolutions in final sectors only

4. The second effect of productivity changes is even more interesting because it generates an endogenous mechanism that explains the rate of growth of demand.

Let us refer first to final commodity *i*, assuming for the time being that the technological revolution occurs solely in this sector. Thus, the capital goods sector achieves only incremental innovations ($\rho_{k_i} = \rho_{tr}$).

Given consumer preferences, the level and rate of change of *per capita* demand for commodity *i* (r_i) depend on the following :

- a general factor, or purchasing power effect. As already noted, when income grows, *per capita* demand for *i* also grows according to an Engel curve path;
- a specific factor, or price effect, given by changes in the price of commodity *i*. To this one should add the changes in the price structure. However, in order to focus on the effects of technological revolutions, this last point is disregarded here.

The technological revolution and the ensuing increase in productivity exert a decisive influence on both factors. The income effect results from the link between wages and productivity increases: if we take the "dynamic standard commodity" as the *numéraire* of the system, the technological revolution in sector *i* exerts an upward pressure on the "standard" rate of productivity growth which will push wages and consumption upwards. The price effect has been examined above.

The precise impact on r_i of the two factors in question depends on two elasticities of demand for commodity *i*: the income elasticity η_i and the (own) price elasticity ε_i. These elasticities vary over time as income changes; however, for the sake of simplicity (and in order not to divert attention from the other aspects that I would like to highlight), in the simulations below η_i and ε_i are kept constant for the whole diffusion period.

The above relationships are summarized in Figure 10, in which the *numéraire* of the system is the "dynamic standard commodity". Since productivity growth follows a long-wave pattern, r_i will also reflect the same movement, which in turn will generate an S-shaped curve for physical output.

To show it analytically, let us write the percentage growth rate of demand for commodity *i* with respect to the previous period, taking as *numéraire* the "dynamic standard commodity" and applying formula (IV.12) for the price decrease:

$$\dot{r}_i^{(iw)} = \varepsilon_i \left(\dot{\rho}_i^{(iw)} \omega_1 + \rho_{tr} \omega_2 - \dot{\rho}^* \right) + \eta_i \dot{\rho}^* \quad {}^{34\ 35}$$

In the first term on the right we recognize the price effect, while the second term is the income effect. By rearranging, we obtain :

$$\dot{r}_i^{(iw)} = \varepsilon_i \left(\dot{\rho}_i^{(iw)} \omega_1 + \rho_{tr} \omega_2 \right) + (\eta_i - \varepsilon_i) \dot{\rho}^* \qquad \text{(IV.20)}$$

An examination of this formula shows that the main factor determining the evolution of $\dot{r}_i^{(iw)}$ is $\dot{\rho}_i^{(iw)}$ and, since $\dot{\rho}_i^{(iw)}$ follows a long-wave pattern (formula (IV.3) and Figure 7), this change will also appear in the growth rate of demand.[36] In fact, when the technological revolution concerns only one sector *i*, the "standard" rate of growth of productivity (ρ^*) is quite small and very near to the trend growth of productivity (0.5-1% per year, as assumed in this paper). The term $(\eta_i - \varepsilon_i)$ is also small. In fact, Bosworth's (1987) survey of empirical studies shows that income elasticity of demand is higher than 1.5 only in few instances (durable goods and services)[37] and that price elasticity is usually less than one. We can thus realistically expect that $(\eta_i - \varepsilon_i)$ is also less than one in most of the relevant cases.

To facilitate numerical simulations, let us rewrite formula (IV.20), adopting as *numéraire* for prices any commodity *h* unaffected by the technological revolution. Relying now on formula (IV.13) for price changes, we have:

$$\dot{r}_i^{(iw)} = \varepsilon_i \dot{\rho}_i^{(iw)} \omega_1 + (\eta_i - \varepsilon_i \omega_1) \rho_{tr} \qquad \text{(IV.21)}$$

This expression for the rate of change of demand for commodity *i* can be made more explicit by substituting $\dot{\rho}_i^{(iw)}$ with the expression given by formula (IV.3).

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34 *The first term on the right of this formula is positive because it is the product of the price elasticity of demand, which is negative, and the percentage rate of change of price, which is also negative. However, I adopt here the usual convention of considering the* ***absolute value*** *of* ε_i.

35 *Let us remember that the percentage change of "standard" productivity is now written without the subscript for the sector in which the technological revolution occurs.*

36 *As noted above, coefficient* ω_1 *reduces the size of productivity changes but the bell-shaped pattern of* $\dot{\rho}_i^{(iw)}$ *remains.*

37 *In any case, most services fall outside the range of goods that could be concerned by a technological revolution.*

Fig. 10

From the technological revolution to demand and output

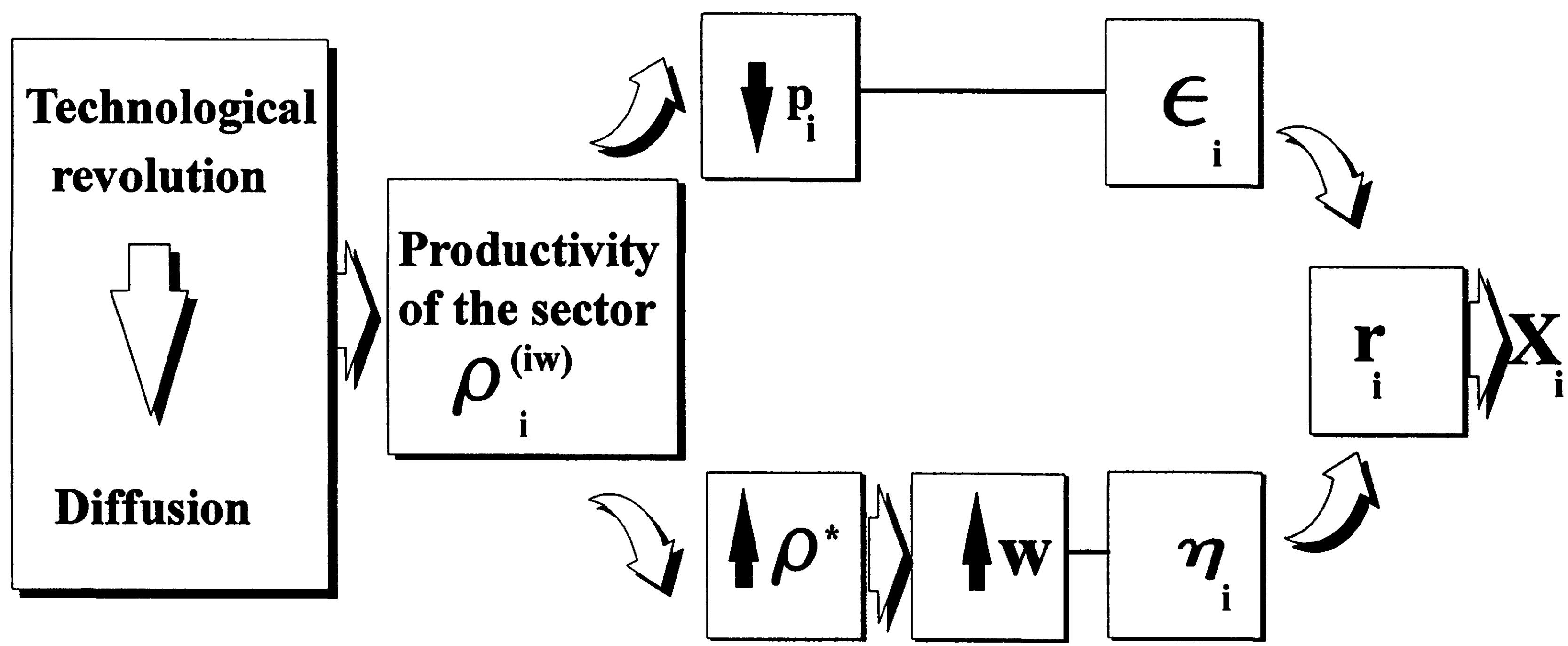
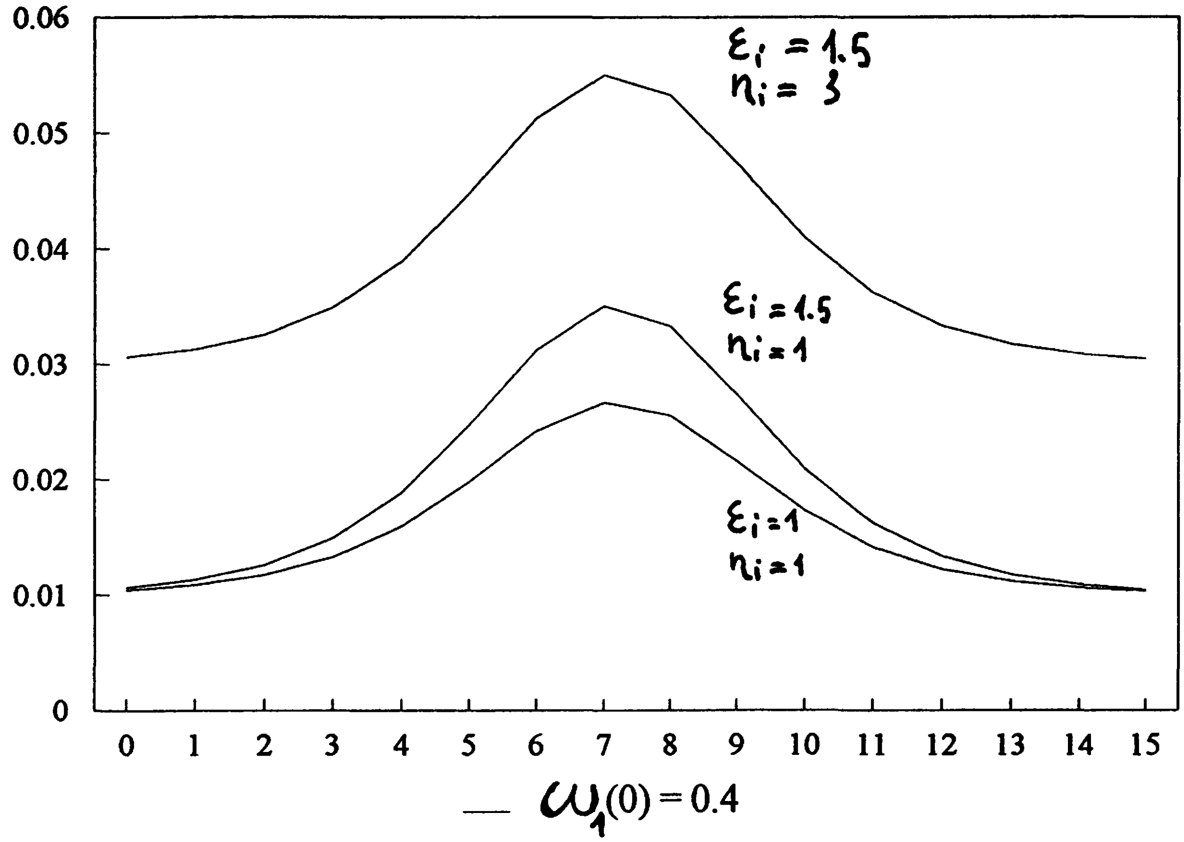


Fig. 11: Rate of change of demand
when there is a technological revolution



Instead of doing this, I prefer to provide an illustration in Figure 11, using the usual logistic for the diffusion function, assuming a productivity shock of 30% ($\Delta_i = 0.3$), setting $\omega_1 = 0.4$ at t = 0, and giving arbitrary values to η_i and ε_i.

5. The physical output of *final commodity i* displays a long-wave (S-shaped) profile. To demonstrate this, let us assume that the population is constant (g = 0)[38] and modify formula (II.29) to take into consideration the new expression for the rate of increase of demand (formula IV.20). Indicating by $r_i^{(iw)}$ the average rate of change from the beginning to period *t*, we have :

$$X_i(t) = IC3_i \; e^{r_i^{(iw)} t} \qquad \text{(IV.22)}$$

where $IC3_i$ is the level of demand at *t* = 0: $IC3_i = a_{in}(0).X_n(0)$

For *capital goods*, the result is :

$$X_{k_i}(t) = \left(\dot{r}_i^{(iw)} + \frac{1}{T_i} \right) D4_i . IC3_i \; e^{r_i^{(iw)} t} \qquad \text{(IV.23)}$$

where: $\dot{r}_i^{(iw)}$ is given by formula (IV.20)

$$D4_i = \frac{T_{k_i}}{T_{k_i} - \gamma_i - \dot{r}_i^{(iw)} \quad \gamma_i T_{k_i}}$$

Figure12a and 12b provide an illustration of the changes in physical output in sectors *i* and k_i, using the data given in Figure 11 for the growth rate of demand. The most striking aspect is that sector k_i evolves in a cyclical-like manner around the long-wave pattern displayed by sector *i*. This interesting path is due to the fact that the accelerator $\left[(\dot{r}_i^{(iw)} + 1/T_i) \; D4_i \right]$ is "bell-shaped", with a range of variation which could be quite large.[39] Thus, it is not necessary to have time-lags for X_{k_i} to show cyclical fluctuations.

6. *Employment* is obtained from formulae (II.31) and (II.32), in which demand and productivity are shaped by the technological revolution.

(a) For *final sector i* we have

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38 *This hypothesis of a constant population will be maintained for the rest of this paper.*

39 *For instance, a numerical simulation based on the following parameters : $T_i = 12$; $T_{ki} = 10$; $\gamma_i = 2$; ω_1 (0) = 0.4 and $\dot{r}_i^{(iw)}$ taken from Figure 10 ($\Delta_i = 0.3$; $\varepsilon_i = 1.5$; $\eta_i = 1$) shows that the "accelerator" term at t = 7 is 34% higher than the level at t = 0.*
As already stated, the above magnitudes for T_i, T_{ki} and γ_i will be used in the simulations which follow.

Fig. 12 a: Physical output of sectors i and k_i (indices)
$\varepsilon_i = \eta_i = 1; \quad \omega_1(0) = 0.4$

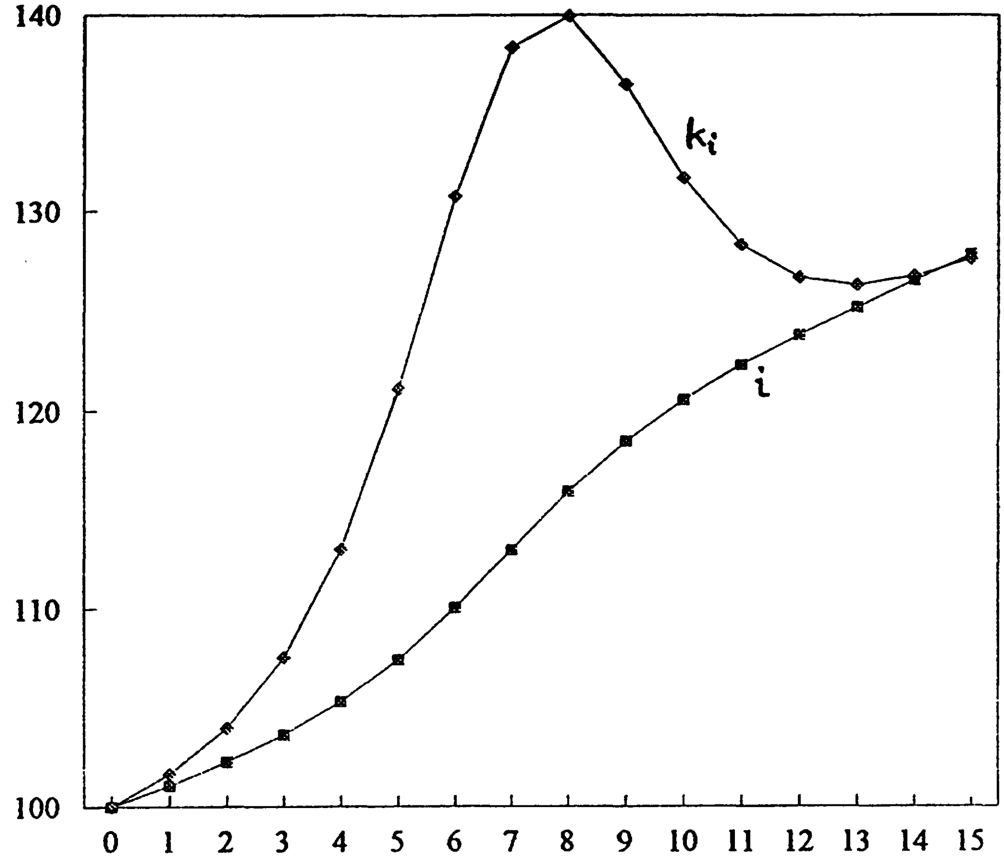
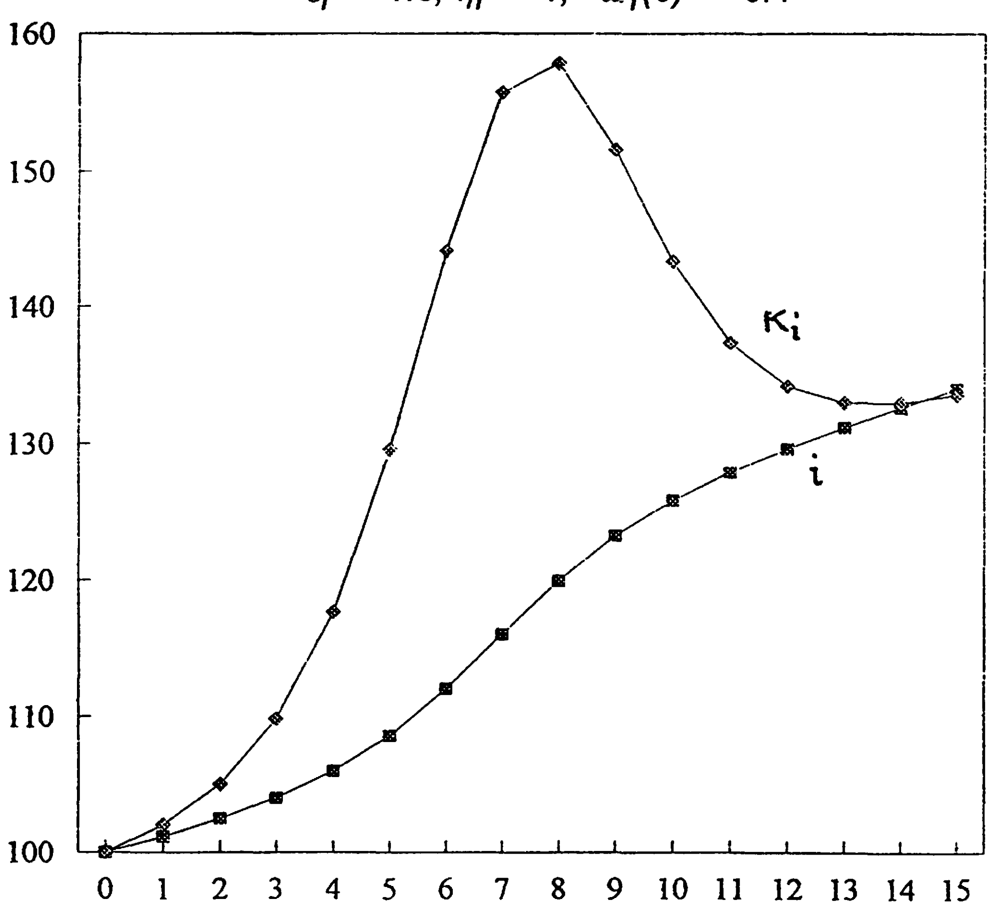


Fig. 12 b: Physical output of sectors i and k_i (indices)
$\varepsilon_i = 1.5; \ \eta_i = 1; \quad \omega_1(0) = 0.4$



$$E_i(t) = E_i(t-1)\ e^{(r_i^{(iw)} - \rho_i^{(iw)})\, t} \qquad \text{(IV.24)}$$

where :

IC1i stands for the initial employment conditions: $IC1_i = a_{ni}(0)\ a_{in}(0)\ X_n(0)$

Formula (IV.24) can be alternatively stated as follows:

$$E_i(t) = E_i(t\text{-}1)\ e^{(\dot{r}_i^{(iw)} - \dot{\rho}_i^{(iw)})} \qquad \text{(IV.25)}$$

when $t = 0$, $E_i(0) = IC1_i$ $\qquad t = 1, 2, \ldots, T$

Writing in full the exponent (taking formula (IV.21) for the rate of increase of demand with respect to the previous period), we see that at period *t* employment increases if:

$$\varepsilon_i\ \dot{\rho}_i^{(iw)}\ \omega_1 + (\eta_i - \varepsilon_i\,\omega_1)\ \rho_{tr} > \dot{\rho}_i^{(iw)}$$

This can happen provided that ε_i , η_i and ω_i are sufficiently high; since such high values are quite rare in practice (Bosworth, 1987), this means that the most likely outcome of a technological revolution in sector *i* is a decline in employment. Numerical simulations based on the usual values for the parameters show that, when $\omega_1(0)$ is 0.2 or 0.4, employment increases only when $\varepsilon_i = 1.5$ and $\eta_i = 3$; when $\varepsilon_i = \eta_i = 1$ or $\varepsilon_i = 1.5$, $\eta_i = 1$, employment declines according to an inverted logistic pattern. Taking $\omega_1(0) = 0.8$, employment declines slightly for $\varepsilon_i = \eta_i = 1$ while it increases for higher price and income elasticities of demand.[40]

(b) For the *capital goods* sector, let us refer to formula (II.32), remembering that $\rho_{k_i} = \rho_{tr}$.

$$E_{k_i}(t) = D4_i\,(\dot{r}_i^{(iw)} + 1/T_i)\ IC2_i\ e^{(r_i^{(iw)} - \rho_{tr})\, t} \qquad \text{(IV.26)}$$

where $IC2_i = (a_{nk_i}/a_{ni})\ IC1_i$

We notice, first of all, the accelerator term as in formula (IV.23). Moreover, contrary to what happens for sector *i* (formula IV.24), the positive impetus to employment stemming from the rate of increase of demand is only slightly offset by the increase in productivity . Employment thus displays a cyclical feature similar to that in Figure 11 (with a peak at *t* = 8) and increases even when employment in sector *i* declines. The level at the final period (T = 15) depends on the degree of mechanization of sector *i* as well as on the price and income elasticities of demand.

For instance, taking the usual values for the productivity function ($\Delta_i = 0.3$) and for T_i, T_{ki} and γ_i, when $\omega_1(0) = 0.4$, at T = 15 employment in sector k_i exceeds its initial level by :

- 9.1% for $\varepsilon_i = \eta_i = 1$ (+ 28.2% at its peak);
- 14% for $\varepsilon_i = 1.5$ and $\eta_i = 1$ (+ 44.2% at its peak);
- 54% for $\varepsilon_i = 1.5$ and $\eta_i = 3$ (+ 64.0% at its peak).

(c) The *overall effect* on employment resulting the technological revolution

40 *An early attempt to deal with these problems is found in Falkinger (1987).*

in sector *i* is the sum of the levels derived from formulae (IV.24) and (IV.26). Unfortunately, the simple addition of these two expressions does not allow us to reach general conclusions since everything depends on the relative size of the two sectors. We have thus to rely on numerical simulations based on alternative assumptions regarding the degree of mechanization of the sectors concerned as well as the magnitudes of the price and income elasticities of demand.

In the examples which follow, the size of employment in sector k_i with respect to sector *i* is determined on this basis:

$$IC2_i = (a_{nk_i} / a_{ni})\ IC1_i = \frac{\omega_2(0)}{\omega_1(0)\ C3i\ C2_i}\ IC1_i$$

where $C2_i$ and $C3_i$ have been calculated with $\pi = 0.2$ and taking the usual values for T_{k_i}, T_i and γ_i[41]

$IC1_i = 100$

With a high or medium degree of mechanization in sector *i* ($\omega_1(0) = 0.20$ and $\omega_1(0) = 0.40$) and price and income elasticities of demand of between 1 and 1.5, total employment in *subsystem i* (i.e. sectors *i* and k_i)[42]tends to decline along a cyclical path: there is a small increase from the beginning to just before the mid-point of the diffusion period, and then a steady decline. As we saw before when considering the sectors separately, total employment increases for high values of the elasticities of demand. For instance, when $\eta_i = 3$ and $\varepsilon_i = 1.5$, total employment is 28% higher during the final period (t = 15) than at the beginning when $\omega_1(0) = 0.4$, and 27% higher when $\omega_1(0) = 0.2$.

When mechanization in sector *i* is low (e.g., $\omega_1(0) = 0.80$), employment declines only when $\varepsilon_i = \eta_i = 1$ (by almost 5% over the 15-year period) and increases for higher values of the elasticities : by 5.5% over the period in question for $\varepsilon_i = 1.5$ and $\eta_i = 1$, and by 43% when $\varepsilon_i = 1.5$ and $\eta_i = 3$.

Figure 13 provides an example for $\omega_1(0) = 0.4$.

All this reinforces the partial result obtained at point *a* above: unless we can rely on very high values of income elasticities of demand, the effect of the technological revolution on subsystem *i* is job-destroying. This is because the increase in employment in the capital goods sector induced by the higher demand for final commodity *i* is not sufficient to compensate for the employment decline in the sector affected by the radical technical change.

To avoid giving the impression that all these results are *ad hoc* because they depend on hypothetical values of the parameters, I conclude with a comment on T_i, T_{k_i} and γ_i. A sensitivity analysis based on alternative values for such coefficients shows that, from the point of view of the results in terms of output and employment, the first two coefficients indeed play a minor role. In fact, calculating *coeteris paribus* the term $D4_i$ for : $5 \leq T_{k_i} \leq 15$, I have found that the level of $D4_i$ is somewhat

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41 *Let us remember that, when ω_1 and ω_2 are computed at t = 0, then*

$FC4_i = IC4_i = a_{nki}(0)\ \bar{w}$, *and*

$FC5_i = IC5_i = a_{ni}(0)\ \bar{w}$

42 *As is explained in Appendix 1, "subsystem" is used here in accordance with Sraffa (1960, p. 89) as that part of an economic system formed by "a smaller self-replacing system the net product of which consists of only one kind of commodity".*

Fig. 13: Total employment in subsystem *i* when the technological revolution appears only in final sector
$\omega_1(0)$ = 0.4 (indices)

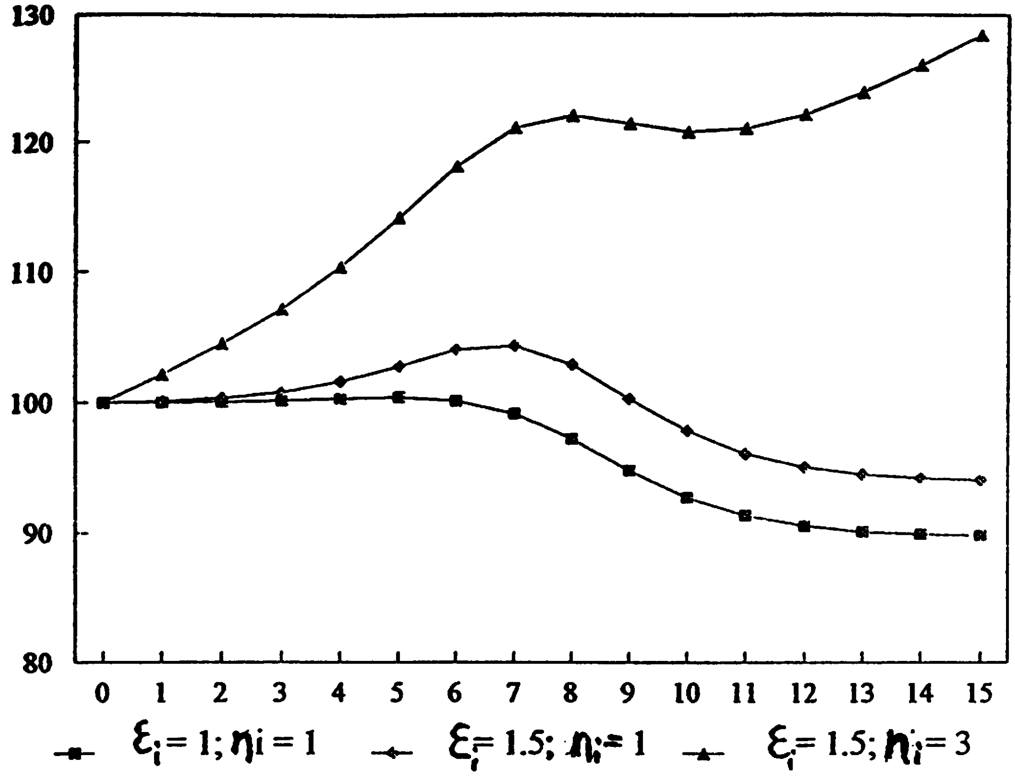
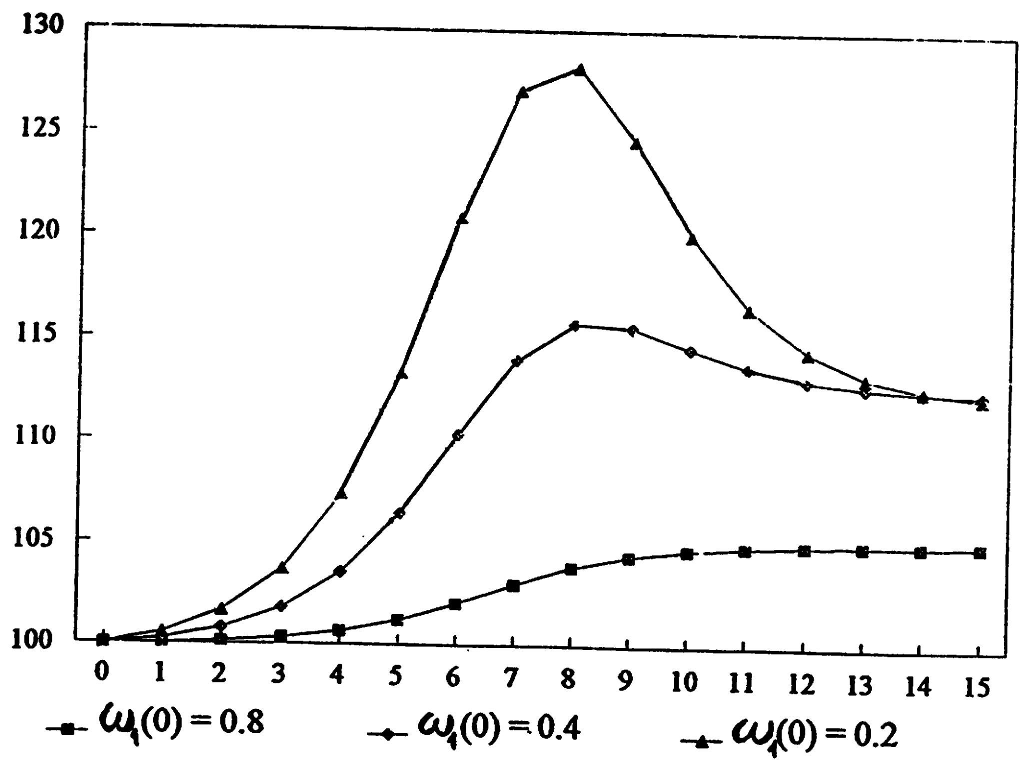


Fig. 14: Total employment in subsystem *i* when the technological revolution appears in capital goods sector only
ε_i = η_i = 1 (indices)



different but the evolution over time of this term is practically the same. Changes in T_{k_i} thus determine the size of the capital goods sector but have almost no effect on its dynamic. For the technical coefficient γ_i things are different. In fact, γ_i has a double effect on employment outcome, via the term $C2_i$ above and via the accelerator. Testing alternative values for γ_i, from a very low (γ_i = 0.5) to γ_i = 3 (which is near the maximum level of 3.33 for $C2_i > 0$), it appeared that the size of employment in the capital goods sector can change substantially, but total employment still follows a path which is quite near to what is outlined above. My general conclusions are not, therefore, affected.

(a.3.2) Technological revolution in the capital goods sectors only

7. As regards *demand*, the mechanism is different from the case already studied because a radical innovation in one sector k_i has no direct influence on the demand for the capital goods in question but merely an indirect effect through the increased demand for final commodity *i*. Obviously, the purchasing power effect is still operating.

The chain of causation is the following: the increase in productivity in sector k_i produces a decrease in the price of capital goods (p_{k_i}) which, in turns, reduces the price of the final commodity (p_i), with a corresponding increase in demand for it (r_i) and in the output of sectors *i* and k_i.

Taking the "standard" commodity as *numéraire*, on the basis of formula (IV.14) the percentage increase of demand with respect to the preceding period is :

$$\overset{\bullet(iw)}{r_i} = \varepsilon_i \left(\overset{\bullet(iw)}{\rho_{k_i}} \omega_2 + \rho_{tr}\, \omega_1\right) + (\eta_i - \varepsilon_i)\, \overset{\bullet *}{\rho} \qquad \text{(IV.27)}$$

This is similar to formula (IV.20) above and the same comments apply *mutatis mutandis.* It is worth adding that, when the degree of mechanization of sector *i* is medium or high ($\omega_1(0)$ = 0.4 or 0.2, for instance), the increase in demand (formula (IV.27)) is now higher than before (formula (IV.20)), particularly for the steepest part of the diffusion curve. In fact, assuming that the intensity of the technological revolution in sector k_i is the same as it was in sector *i*, the fact that $\omega_2 > \omega_1$ implies that now p_i decreases more than before and demand grows faster.

When the *numéraire* is any commodity *h*, from formula (IV.15) we obtain:

$$\overset{\bullet(iw)}{r_i} = \varepsilon_i \overset{\bullet(iw)}{\rho_{k_i}} \omega_2 + (\eta_i - \varepsilon_i\, \omega_2)\, \rho^{tr} \qquad \text{(IV.28)}$$

8. The *physical output* of sectors *i* and k_i is affected in a similar way to that observed in the case examined at point 5. Formulae (IV.22) and (IV.23) formally apply here, the difference being given by $r_i^{(iw)}$, which is taken from (IV.28). Obviously, X_i and X_{k_i} now grow faster than before, with an higher peak for the cycle followed by X_{k_i}.

9. In spite of the formal similarities, *employment* displays a different pattern from when the technological revolution concerns only sector *i* (point 6 above).

(9.1) For final sector *i*, formula (IV.24) becomes:

$$E_i(t) = IC1_i \; e^{(r_i^{(iw)} - \rho_{tr})t} \qquad \text{(IV.29)}$$

For the capital goods sector:

$$E_{k_i}(t) = D4_i \; (\overset{\bullet(iw)}{r_i} + \frac{1}{T_i}) \; IC2_i \; e^{(r_i^{(iw)} - \rho_{k_i}^{(iw)})\,t} \qquad \text{(IV.30)}$$

Comparing formula (IV.29) with (IV.24), we see that now employment in sector *i* increases constantly. The growth rate of demand is, in fact, higher than before, and $\rho_{tr} < \rho_i^{(iw)}$. For $\omega_1(0) = 0.4$ and $\varepsilon_i = \eta_i = 1$, a numerical simulation with the usual parameters shows that, at T=15, employment is 18% higher than at the beginning; this increase is larger for higher degrees of mechanization. Note that employment grows slightly even when mechanization in sector i is low (i.e. $\omega_1(0) = 0.8$).

In the capital goods sector employment shows a more pronounced cyclical pattern than before (point 6.b), in the sense that the peak is more pronounced while the final level is not always higher than the level at the beginning. This happens when final sector i has a medium or low degree of mechanization (e.g. $\omega_1(0) = 0.4$ or 0.8)[43] and $\varepsilon_i = \eta_i = 1$ or $\varepsilon_i = 1.5$, $\eta_i = 1$. For higher elasticities of demand, $E_{k_i}(T) > E_{k_i}(0)$ in all cases.

(9.2) Total employment in subsystem *i* shows in general a favourable development. The scope of the final outcome as well as its cyclical component are directly related to the price and income elasticities of demand for final commodity i and to the degree of mechanization in this sector.

Figure 14 depicts the case of a unit price and income elasticity of demand with different hypotheses as to the degree of mechanization in sector *i*: it is worth noting the amplitude of the cycle when mechanization in sector *i* is high ($\omega_1(0) = 0.2$).

(a.3.3) Technological revolution in both sectors

This is the case in which the new technology is pervasive. The typical example is the present situation with regard to information technology.

10. *Demand* for final commodity *i* is derived from formulae (IV.17) or (IV.19):

- *"standard commodity" as numéraire*

$$\overset{\bullet(iw)}{r_i} = \varepsilon_i \overset{\bullet(iw)}{\rho_i} + (\eta_i - \varepsilon_i) \overset{\bullet *}{\rho} \qquad \text{(IV.31)}$$

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43 *The reference is to the final commodities sector instead of the capital goods sector because the impetus comes from the former.*

where, as already noted, $\dot{\rho}^{(iw)}$ is the common rate of increase of productivity in sectors *i* and k_i ($\dot{\rho}^{(iw)} = \dot{\rho}_{k_i}^{(iw)} = \dot{\rho}_i^{(iw)}$).

Of course, if the hypothesis on the uniform strength of the technological revolution does not hold, such that

$$\dot{\rho}^{(iw)} < \dot{\rho}_i^{(iw)}\,\omega_1 + \dot{\rho}_{k_i}^{(iw)}\,\omega_2$$

then the increase in demand will be magnified with respect to what results from formula (IV.31), and the converse will occur if the inequality sign is reversed.

• *any commodity h as numéraire*

$$\dot{r}_i^{(iw)} = \varepsilon_i\,\dot{\rho}_i^{(iw)} + (\eta_i - \varepsilon_i)\,\rho_{tr} \qquad \text{(IV.32)}$$

11. The *physical output* of the two sectors shows the well-known pattern: a long-wave profile for X_i and a cycle for X_{k_i}. Since the growth rate of demand is now higher than when the technological revolution is confined to one sector, the long-wave pattern is much more evident and, obviously, the level during the final period is higher.

For instance, taking the usual values for the numerical simulations and $\varepsilon_i = \eta_i = 1$, the output of final commodity at T=15 is now 50.5% higher than the initial level, as against 27.7% when the technological revolution is limited to the sector itself
($\omega_i(0) = 0.4$) or 37% when it occurs only in sector k_i. For lower elasticities, the increase in output is still substantial: for instance, when $\varepsilon_i = \eta_i = 0.5$, at T = 15 the level of output is 23% higher than at t = 0.

The capital goods sector displays similar results for the level at the end of the period, with a much broader cyclical peak (in the above example, at t = 8 output is more than the double the initial level).

12. *Employment* in the final commodities sector is more conveniently studied on the basis of formula (IV.25):

$$E_i(t) = E_i(t-1)\, e^{(\dot{r}_i^{(iw)} - \dot{\rho}_i^{(iw)})} \qquad \text{(IV.25a)}$$

Let us consider the exponent, substituting $\dot{r}_i^{(iw)}$ with (IV.32) and rearranging:

$$\dot{\rho}_i^{(iw)}\,(\varepsilon_i - 1) + (\eta_i - \varepsilon_i)\,\rho_{tr} \qquad \text{(IV.33)}$$

Formula (IV.33) shows that year-on-year changes in employment depend crucially on price and income elasticities of demand. Employment can grow only when these elasticities are sufficiently high, i.e. larger than one. When both elasticities are equal to one, employment remains constant; it declines for ε_i and η_i less than one.

The cyclical pattern in the *capital goods* sector implies that employment can grow substantially even when it is stationary in the final commodities sector (for $\varepsilon_i = \eta_i = 1$). For instance, a numerical simulation with the usual values shows that, at t=7, employment in the capital goods sector is 66% higher than its initial level. Of course, at the end of the period of diffusion of the technological revolution, employment in the capital goods sector has fallen to the level at the outset.

Changes in *total employment* are straightforward. For price and income elasticities higher than one, it increases, with a more or less pronounced cyclical component according to the relative importance of the capital goods sector (which depends on the degree of mechanization of sector *i*). For $\varepsilon_i = \eta_i = 1$ total employment reproduces the cyclical pattern of sector k_i around a flat long-term trend. For ε_i and η_i less than one, it tends to decline. For instance, when $\varepsilon_i = \eta_i = 0.5$, a numerical simulation with the usual values ($\omega_1(0) = 0.4$ for the size of sector k_i) shows a continuous decline in total employment, which, at T = 15, is 18.4% lower than at the beginning (Figure 15). Comparing this outcome with that for output, we see that rapid growth in output is not at all incompatible with a decline in employment.

(*b*) *Sectoral analysis: product innovations*

13. I consider radical product innovations (as opposed to incremental innovations) to mean here that a completely new final product is launched on the market, "a product that is a radical departure from existing ways of performing a service" (Dean, 1950, p. 46). This new commodity may replace another commodity in satisfying a perceived consumer need or may be in response to an entirely new need.

14. The demand for these new commodities does not spring endogenously from the model as in the case of process innovations, but it results essentially from changes in consumer preferences.[44] In long waves and marketing literature (Van Duijn, 1983; Levitt, 1965; Dean, 1950; Mahajan, Muller and Bass, 1990) the usual reference is to the product life-cycle. According to Levitt (1965, p. 81), demand for and sales of new products pass through four stages:

(i) market development (introduction), when the product is first brought to the market;

(ii) growth, when demand begins to accelerate and the size of the total market expands rapidly;

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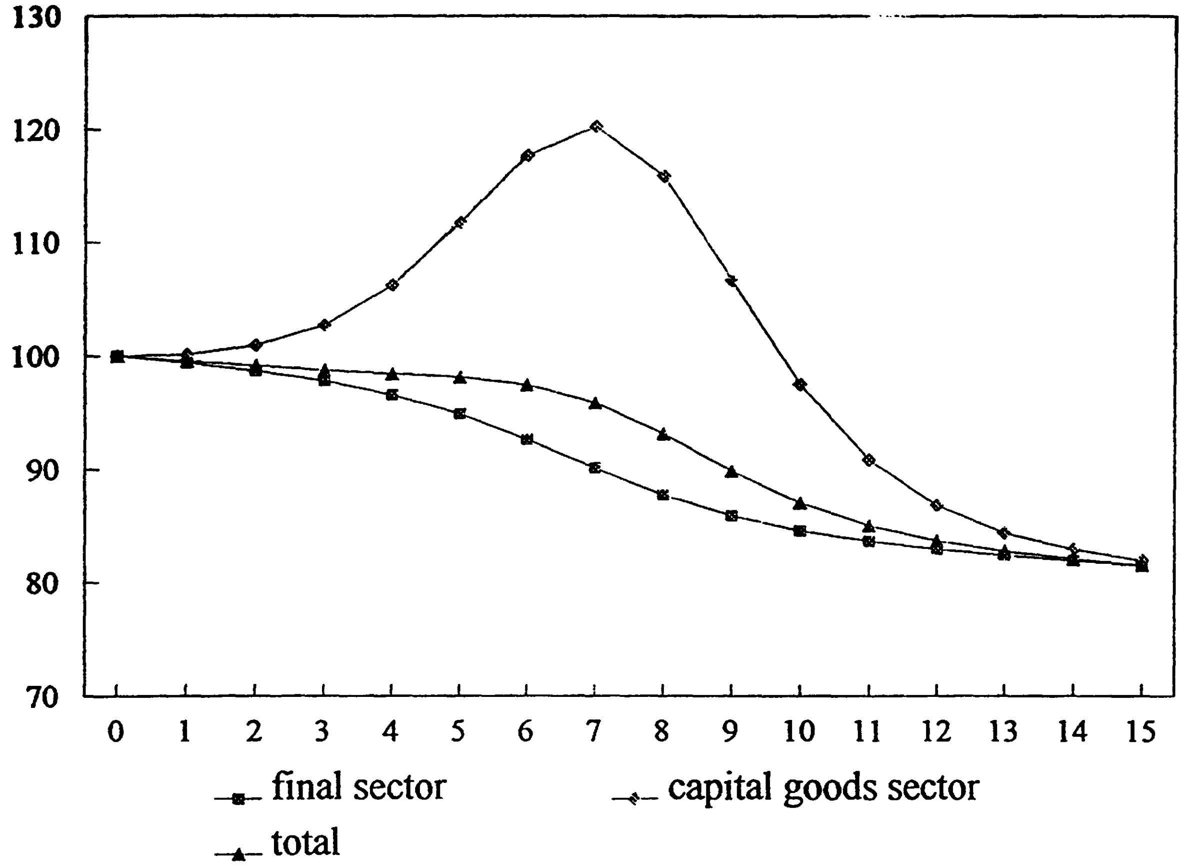
44 *Falkinger (1994) develops another approach in which the demand for new commodities is derived from the hierarchical nature of consumer demand: when people have satisfied higher-priority wants, they turn to new wants. Thus, product innovations must be related to income because demand for new products evolves as demand for old products is saturated. Seen in this way, product innovations are no longer exogenous. (I thank J. Falkinger for drawing my attention to this point).*
This approach could be compatible with the findings of the long-wave theory summarized in Table 1. In fact, during the long stagnation, income inequalities usually widen and this could foster demand for new products.

Fig. 15: Employment
when the technological revolution appears in both sectors
$\varepsilon_i = \eta_i = 0.5;\ \omega_1(0) = 0.4$ *(indices)*



(iii) maturity, when demand levels off and grows, for the most part, only at the replacement and new family-formation rate;

(iv) decline, when the product begins to lose consumer appeal and sales drift downward.

The reasons put forward to explain consumer behaviour in the first and second stages are not so different from those identified above for the S-shaped diffusion of process innovations. First of all, there is the gradual spread among consumers of information on the existence of the new commodity, its characteristics and its appropriateness in satisfying a particular need: it is the "epidemic" model already mentioned (see Stoneman, (1983), for a broad discussion of these models). Next we turn to prices. Very often the introduction of a new product requires heavy investment in research and development as well as considerable expenditure on marketing. In such circumstances, the price at the initial stage in the product life-cycle will frequently be set at a high level to allow the innovator to recoup his costs before too many imitators enter the market.[45] However, this price level, which "skims the cream of the demand", will be progressively abandoned during the later stages of the product life-cycle so as to stimulate demand from other segments of the market. Further price reductions of this kind will be engendered by the growing competion from newcomers as well as by process innovations in the sector concerned and in the corresponding capital goods sector.

In the literature, the demand for radically new products during the first three stages of their life-cycle is represented by a Gompertz curve (e.g. Levitt, 1965); as noted above, this implies that the percentage rate of change with respect to the previous period ($\dot{r}_i^{(np)}$) decreases over time.[46] Unfortunately, it is not possible to add anything precise regarding the magnitudes of the values taken by $\dot{r}_i^{(np)}$ at any period because they depend on the initial level of demand for the new commodity (parameter *a* in formula (III.3)) as well as on the slope of the diffusion curve (parameter *b* of the same formula). The only thing that one can say is that $\dot{r}_i^{(np)}$ will usually be quite high during the first two stages of the product life-cycle.

The length of the diffusion period, i.e. the number of years taken to move from the introduction stage to the maturity stage, varies a great deal from one product to another. Thus, unlike in the case of process innovations, it can no longer be realistically assumed that the maturity stage is reached at the end of the phase at the long-wave during which the innovation was first introduced. Empirical research by Gort and Klepper (1982) based on a sample of "basic" product innovations first commercially introduced between 1887 and 1960 shows that, on average, the maturity stage was reached in 37 years.[47]

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45 *The strategic choice regarding the initial price level is discussed by Dean (1950, p. 49 et seq.)*

46 *The (instantaneous) percentage rate of change with respect to the previous period is, from formula (III.3):* $C\ b^t$
where C *is a constant:* $C = ln(b)\ ln(a)$

47 *However, the interval required for successful imitation has systematically declined over time. While the overall average length of the first stage (introduction) is 14.4 years, for products introduced before 1930 this interval was 23.1 years; it is 9.6 years for those introduced in the period 1930-39 and only 4.9 years for products introduced in 1940 or later (Gort and Klepper, 1982, p. 640)*

15. New products can be manufactured using an existing technique or a completely new technique. In both cases only incremental process innovations take place and the rate of increase of productivity is ρ_{tr}. This is referred to below as the "pure" case.

Alternatively, when the technology which is becomng dominant in the economic system is pervasive in nature (as it is at present the case with information technologies), the manufacture of the new product will also be affected by radical process innovations. Empirical findings show that, in the present circumstances, this "mixed" case is the most likely. This transpires, for instance, from Edquist's study on Swedish industry (quoted by Edquist, 1993) and from Gort and Klepper (1982): both studies noticed that the market development of new products is positively correlated to high productivity levels and high productivity growth.[48]

(b.1) The "pure" case: product innovations alone

16. *Demand* is completely exogenous: its evolution is described by the product life-cycle and relies essentially on changes in consumer preferences.

17. The *physical output* of the new commodity does not present any conceptual problem. All that needs to be done is to insert into formulae (IV.22) and (IV.23) the rates of change of demand $r_i^{(np)}$ and $\dot{r}_i^{(np)}$. Since these rates are derived from a Gompertz curve, the output of the final commodity will reflet closely this movement, while the output of the capital goods will exhibit the well-known cycle. The difference compared with process innovations is that the diffusion could now be much longer and could extend, for instance, over the entire stagnation phase of the long wave (which I have conventionally assumed to be 25 years) or even beyond.

18. *Employment* is also straightforward:

$$E_i(t) = IC1_i\, e^{(r_i^{(np)} - \rho_{tr})t} \tag{IV.34}$$

$$E_{k_i}(t) = D4_i\,(\dot{r}_i^{(np)} + \frac{1}{T_i})\, IC2_i\, e^{(r_i^{(np)} - \rho_{tr})\,t} \tag{IV.35}$$

Since $r_i^{(np)} > \rho_{tr}$, employment increases in both sectors: in the "pure" case, product innovations are thus a major source of employment.

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48 *In Edquist this appears directly, while in Gort and Klepper the productivity growth is captured by a decline in the relative prices of the new products.*

(b.2) The "mixed" case: product innovations are coupled with process innovations

On this point I shall be very brief because the analysis is very similar to sections (a.3.1), (a.3.2) and (a.3.3) above.

(b.2.1) Demand and physical output

19. *Demand* now has two additive components because the process of changing consumer preferences (the exogenous part, described by a Gompertz curve) is coupled with the demand stimulus resulting from the technological revolution (the price and income effects, or the endogenous component):

$$\dot{r}_i^{(np)} = \dot{r}_i^{(ex)} + \dot{r}_i^{(iw)} \qquad \text{(IV.36)}$$

where $\dot{r}_i^{(ex)}$ is the (instantaneous) percentage rate of change in the exogenous component of demand.

Taking the case in which the technological revolution occurs in the final commodities sector as well as in the capital goods sector (formula (IV.32)), the preceding formula becomes:

$$\dot{r}_i^{(np)} = \dot{r}_i^{(ex)} + \varepsilon_i \, \rho^{(iw)} + (\eta_i - \varepsilon_i)\, \rho_{tr} \qquad \text{(IV.37)}$$

During the first few years of the diffusion period $\dot{r}_i^{(ex)}$ will be the dominant factor shaping $\dot{r}_i^{(np)}$ because, as already noted, $\dot{r}_i^{(ex)}$ is quite high while $\dot{r}_i^{(iw)}$ is low. Moreover, since the diffusion period for the new product could be longer that the time span required by the diffusion of the process innovations, when the technological revolution has come to the end, the demand for the new product could continue to grow substantially under the influence of $\dot{r}_i^{(ex)}$

20. As for *physical output*, I would simply note that, for the final commodity, we find once again the S-shaped movement resulting from the exogenous and the endogenous components of demand. Output in the capital goods sector displays the usual cycle around the long-wave pattern followed by X_i.

(b.2.2) Employment

21. Let us consider the most realistic case in which the technological revolution is pervasive and occurs in both sectors *i* and k_i.

For the *final commodities sector* we have as usual:

$$E_i(t) = E_i(t-1)\; e^{\dot{r}_i^{(np)} \; {}^{\bullet(iw)} - \rho} \qquad \text{(IV.38)}$$

Writing in full the exponent on the basis of formula (IV.37) and rearranging, we have:

$$\overset{\bullet(np)}{r_i} - \overset{\bullet(iw)}{\rho} = \overset{\bullet(ex)}{r_i} + \overset{\bullet(iw)}{\rho} \quad (\varepsilon_i - 1) + (\eta_i - \varepsilon_i)\,\rho_{tr} \qquad \text{(IV.39)}$$

Comparing (IV.39) with (IV.33), we see that the only difference concerns the term $\overset{\bullet(ex)}{r_i}$. Thus, the comments in point 12 on the changes in employment stemming from process innovations (the endogenous components) still hold. I would just add that, even when the price and income elasticities of demand are equal to or less than one (and when, as a result, the endogenous component of employment is zero or negative), employment in sector *i* could increase under the influence of the exogenous component of demand provided that:

$$\overset{\bullet(ex)}{r_i} > \left| \overset{\bullet(iw)}{\rho} \quad (\varepsilon_i - 1) + (\eta_i - \varepsilon_i)\,\rho_{tr} \right| \qquad \text{(IV.40)}$$

Assuming, so as to simplify matters, that the diffusion of product and process innovations starts at the same time, employment in sector *i* will certainly rise in the first stage of the product life-cycle. When the product life-cycle is longer that the diffusion period for the process innovations, employment could also increase during the period beyond the end of that period if:

$$\overset{\bullet(ex)}{r_i} > \left| \rho_{tr}\,(\eta_i - 1) \right| \qquad \text{(IV.41)}$$

For the period covering the intermediate stages of the product life-cycle, the case in which the two elasticities are less than one does not permit a clear-cut outcome: depending on the value taken by ε_i, η_i and $\overset{\bullet(ex)}{r_i}$, employment could increase or stagnate.

In the case of *capital goods*, the only thing to note is that they add a cyclical component (the accelerator term) to the general trends outlined above.

In conclusion, we can say that, in spite of some uncertain cases, product innovations on the whole offer positive prospects for employment, even when the effects of process innovations are job-destroying.

22. The case in which the radical process innovations are not pervasive and thus affect only sector *i* or k_i do not require special analysis. It is sufficient to rewrite formula (IV.39) *mutatis mutandis*, i.e. adding $\overset{\bullet(ex)}{r_i}$ to the demand functions (formulae (IV.18) and (IV.28)) and taking the appropriate rate of productivity growth.

The above general conclusion holds: the exogenous component of demand could more than offset the job-destroying effects of radical process innovations.

(c) Outline of the overall dynamic of the system

The purpose of this section is not to reconstruct the long-wave movement, a task which is beyond the limits of this paper and which includes many institutional aspects, but to address those aspects which are relevant for my attempt to introduce long-waves into Pasinetti's model. I will, therefore, consider only the effects of the diffusion of the technological revolution (which is nevertheless one of the main factors explaining the appearance of long waves) in order to give some broad indications as to how the sectoral trends already examined generate a long upswing for the whole economy. The transition from long expansion to long stagnation is thus left out of my analysis (for this see Mandel, 1976, 1980).[49]

23. Starting with *process innovations*, the first element which characterizes the overall dynamic is the growing number of sectors affected by the technological revolution (see Table 1 above). If the new technology is pervasive, a substantial part of the economy (including services) will operate on the new technical base by the end of the long stagnation . The diffusion of the "dominant" technology forming the new "technological paradigm" (Freeman and Perez, 1988; Dosi, 1984) is further reinforced by the appearance of a cluster of radical innovations in other fields that are not necessarily related to the "core" of the technological revolution (Schumpeter, 1977).

24. The consequence of the inter-sectoral diffusion of the technological revolution is a change in the composition of the "dynamic standard commodity" and a corresponding acceleration in the "standard" growth rate of productivity. The changes in productivity associated with the "dynamic standard commodity" will reflect the S-shaped productivity functions of the individual sectors affected by the technological revolution.

This modifies my previous analysis, where, to facilitate the numerical simulations, the *numéraire* was any commodity *h* not affected by radical technical change. In fact, since the "standard" growth rate of productivity is now much more important, this implies that:

- the price effect of the demand functions is reduced. In fact, since $\rho^* > \rho_{tr}$, in terms of the new *numéraire* the decline in the prices of the commodities affected by the technological revolution is less marked,
- the income effect is magnified and becomes increasingly important as the technological revolution extends to other sectors of the economy.

As a matter of fact, process innovations occur throughout the entire long wave (Table 1). This means that the two effects arising from the increase in the "standard" rate of productivity are constantly being fuelled. During the first phase of long

49 *By disregarding this part of the long-wave theory, we need not introduce the effects of the saturation of demand for many commodities, and this justifies my previous assumption of constant income elasticity of demand for the numerical simulations.*
Falkinger's (1994) model, in which income distribution and demand for new commodities play a central role in the long-run growth path of the economy, helps to complete the picture.

stagnation (the depression) the stimulus comes from existing industries; when the number of innovations from these sectors falls, there is a wave of innovations from "basic" sectors, intensifying in the first phase of the long expansion, and so on (Table 1).

25. The other major effect of the inter-sectoral diffusion of the technological revolution is on physical output. We have seen that, when a sector is affected by such technological change, its output follows a long-wave path. The multiplication of this phenomenon during the long stagnation sets in motion a cumulative process of growth which is then further sustained by process innovations in "basic" sectors during the prosperity phase of the long expansion. To this should be added the general growth in demand associated with the fulfilment of the equilibrium condition for wages, i.e. the wage rate follows the "standard" growth rate of productivity. This effect operates throughout the long wave and becomes stronger when radical technical change intensifies.

Being the aggregation of all sectoral outputs, aggregate output will exhibit the familiar S-shaped profile, which now extends over the (conventionally assumed) fifty years of the long-wave. The capital goods sectors add a "rolling" component to the basic trend set by the final commodities sectors.

26. *Product innovations* strongly reinforce the tendencies outlined above, particularly during the long stagnation because, as Table 1 shows, it is in this phase of the long wave that the propensity for such innovations to materialize is greater.

To appreciate their overall impact, it is essential to distinguish between product innovations in existing industries and product innovations giving rise to new industries. In fact, in the former case a (completely) new product satisfies a need which was already met by another commodity. Enterprises in this sector thus progressively substitute the old commodity with the new one. The contribution of the sector to aggregate output in the economy is the difference between the expanding output of the new commodity and the declining output of the old commodity.

Product innovations which coincide with the creation of new industries satisfy a new need: their output thus therefore represents a net addition to aggregate output. Since such innovations are more frequent during the recovery phase of the long stagnation, their contribution to the incipient process of growth could be appreciable.

27. *Total employment* is the most puzzling part of the story because it is influenced by countervailing and uncertain factors.

(a) Let us start with *process innovations* and consider the realistic case in which the new technology is pervasive (i.e. it concerns both final commodities and capital goods sectors as well as a large part of the economy). This technological revolution has two effects on the level of employment in the economic system: a general effect, with positive repercussions on employment, and a specific effect, with neutral or negative repercussions. Let us first consider the latter.

The sectoral analysis has shown that total employment displays a long-term positive trend only when the price and income elasticities of demand are high (greater than one). Since empirical evidence indicates that such high values of the elasticities appear only in a few cases, one can expect that, for the whole economic system, the trend will be flat or at best slightly positive, with a more or less pronounced cycle due to the capital goods sector.

The general effect stems from the increase in aggregate demand resulting from the positive influence of the technological revolution on the "standard" growth rate of productivity and on wages. In such circumstances, total employment will be underpinned by the sectors not concerned by radical technical change. In fact, demand there will increase, but this will not be offset by an analogous increase in productivity, which continues to grow at the trend rate. The magnitude of this effect depends on the relative importance of the sectors in question with respect to the total economy.

(b) For *product innovations* the outcome is well defined, in the sense that, even when process innovations also extend to the manufacture of new products, we can expect a positive effect on employment.

(c) To sum up, one can tentatively say that, during the long stagnation, the "specific" effect will prevail while, during the long expansion, the main stimulus will come from the demand side. To be more precise :

• in the depression phase of the long stagnation employment will be roughly stationary, for three reasons:

- process innovations in existing industries will not contribute appreciably to the growth of employment;

- the same will be true of product innovations in existing industries. The new products, in fact, replace some old ones and, in any case, their relative importance is rather weak because they are at the beginning of the product life-cycle;

- the demand effect is also rather weak, especially during the first years of the phase;

• during the recovery phase employment will increase under the impact of product innovations in new industries, which will be reinforced by the same type of innovations in existing industries. To this has to be added the demand effect, which has meanwhile gained momentum.

It is perhaps worth repeating that this is only a partial picture of the long-wave, a picture which considers only the effects of the technological revolution. For instance, the fact that in the depression technical change has a rather neutral effect on employment does not prevent employment from actually falling for other reasons (e.g. sectoral restructuring and bankruptcies).

28. To conclude, I would like to stress that my analysis is not inconsistent with the more elaborate theory of long-waves, which considers actual capitalist economies instead of the "natural" system.

The case in which this complementarity is the most obvious is the Schumpeterian interpretation of long-waves, focussing on the "techno-economic" paradigms (Dosi, 1988; Freeman, 1982; Freeman and Perez, 1988), but this is also apparent in Mandel's (1976, 1980) contribution, in which social relations and conflicts play a central role. According to this author, three conditions need to be met in order to trigger a new long-term expansion : (i) a technological revolution; (ii) an exceptional long-term increase in the actual and expected average rate of profit; (iii) a long-term expansion of demand. The second and third conditions are the prerequisites for a massive implementation of radical innovations, while the first depends on a number of exogenous factors (Mandel, 1976, Vol. I, pp. 224-225).

If we compare these findings with the results of the present paper, we will see that, leaving aside the profit rate condition, the expansion of demand now has an endogenous explanation at the deeper level of the "natural" system. "Institutional" analysis is thus embedded in a classical "high" theory and receives new strength from it.

V. CONCLUSIONS

1. Long-waves are introduced into Pasinetti's model of structural change on the assumption that productivity growth is driven essentially by technological revolutions. Radical process innovations result in a leap in productivity for the innovator and progressively extend throughout the sector concerned according to a non-linear path. Demand for completely new products follows a similar profile, which is determined by the product life-cycle.

2. The argument is developed at the logical stage which precedes institutions (the "natural" system) so as to identify the basic forces determining the trend and the boundaries for the actual movements in prices, physical quantities and employment.

The formal results are illustrated by numerical examples based on logistic diffusion functions for technical change and various assumptions regarding the degree of mechanization of the sectors as well as the price and income elasticities of demand.

The enquiry is conducted mainly at the sectoral level; however, at the end of the paper it is shown that the outcome of the sectoral trends discovered is a long-wave pattern for the whole economic system. This is not, of course, a reconstruction of the complete long-wave movement, but rather an analysis of the effects of the technological revolutions in Pasinetti's "natural" system.

3. Three general results should be mentioned. The first one is the overwhelming importance of the pattern of diffusion of the technological revolution. It is, in fact, this element that shapes the productivity curve of the sector, which, in turn, determines the trend and form of the price movement as well as the scope for the growth of demand.

This last aspect, which constitutes the second general result, deserves particular attention. The technological revolution and the ensuing increase in productivity generate an endogenous mechanism explaining the growth rate of demand via:

- a purchasing power effect which operates when wages are linked to the average productivity growth of the system (the "standard" rate of growth);
- a price effect for the commodity directly concerned by the technological revolution.

The third result is the importance of the price and income elasticity of demand, which can amplify or reduce the basic stimulus coming from productivity.

4. As for process innovations, the sectoral analysis shows that *physical output* in the final commodities sectors follows a long-wave (S-shaped) profile which is more or less pronounced according to the values taken by the price and income elasticities of demand.

Physical output in the capital goods sectors is characterized by a business-cycle pattern around the long-wave path displayed by the corresponding final commodities sector.

The progressive inter-sectoral diffusion of such innovations sets in motion a cumulative process of growth that helps the system climb out of the long stagnation.

5. The *employment* outcome is complex.

(a) The clearest case involves *product* innovations, which result in a growing employment trend both at sectoral and aggregate level.

When there are no radical process innovations in the vertically integrated sector producing the new commodity (the "pure" case), product innovations are a major source of employment. When, on the contrary, the output of the new commodity is concerned by radical process innovations (the "mixed" case), the situation is not unambiguous. Nevertheless, even in this case the prospects for employment are on the whole positive because the increase in demand for the new commodity tends to outweigh the job-destroying effect of process innovations.

(b) For *process* innovations the results are more uncertain because employment is exposed to a number of conflicting pressures. I should mention in particular the price and income elasticities of demand and the degree of mechanization in final commodities sectors.

(b.1) At sectoral level I have found that, when the technological revolution affects only one sector (final commodities or capital goods), the best outcome is when this technical change concerns solely the capital goods sector because, in this case, total employment in subsystem *i* (i.e. the final commodities sector plus the corresponding capital goods sector) usually increases. However, when the technological revolution is confined to the *final* sector, numerical simulations show that, for a "medium" or high degree of mechanization in this sector and for price and income elasticities of demand between 1 and 1.5, total employment in subsystem *i* follows a long-term declining trend, with a cyclical component given by the capital goods sector. Total employment tends to grow only with higher levels of such elasticities although these are quite uncommon in practice.

Numerical simulations carried out for the realistic case in which the technological revolution affects both final commodities and capital goods sectors lead to the conclusion that, in the most common cases (i.e. when the price and income elasticities of demand are equal to one or less), total employment stagnates or declines, with a cyclical component. Comparing this result with that for output, we notice that, for the vertically integrated sector concerned, substantial growth in output may very well be compatible with stagnating or even declining employment. This is because the rate of change of demand which is (endogenously) generated by the technological revolution is sufficiently high to raise output, but not large enough to compensate for the employment-reducing effect of productivity increases.

(b.2) At macroeconomic level, analysis of the inter-sectoral diffusion of the technological revolution in the case of pervasive technological change has shown two conflicting influences on aggregate employment:

- a specific effect reflecting the situation in the sectors directly affected by the technological revolution;

- a general effect resulting from the following sequence: increase in productivity in the sectors affected by the technological revolution; ensuing increase in the "standard" growth rate of productivity; corresponding increase in wages and in aggregate demand.

For the most common values of the price and income elasticities of demand (i.e. for ε_i and η_i equal to or less than one), the first effect will be conducive to a rather flat trend for total employment, whereas the second effect will push up employment because the extra demand will also be directed towards sectors untouched by radical technical change and hence not suffering from technological job redundancies. The extent of such job creation depends on the relative importance of these "traditional" sectors. If their share of the total economy is limited because the technological revolution is pervasive, then the prevailing macroeconomic tendency could be a very slow increase in or a stagnating level of employment, even during the long expansion.[50] Thus, one should not be too impressed if, for some years, total employment rises under the impact of the capital goods sector, because this is only a cyclical movement which does not undermine the basic trend.

It is perhaps worth noting, to conclude on this topic, that the above results on the evolution of employment do not depend on wage behaviour. In fact, as explained in appendix I (chapter IV), the choice of technique is not influenced by the wage rate. Moreover, the kind of technical change considered here (radical innovations) materializes in a so called "dominant" technique, *i.e.* a technique which, for any given wage rate, yields a rate of profit higher than with any other technique (Pasinetti 1977, p. 159).

6. The theoretical analysis carried out in this paper has at least three implications for economic policy: (a) the action to foster the diffusion of the technological revolution; (b) the action on the employment front; (c) the guiding role of public authorities in meeting the equilibrium condition for wages.

(a) We have seen that the diffusion of radical technical change is conducive to growth. The faster the diffusion, the sooner growth will materialize. However, several obstacles can delay innovations; public authorities can influence the process directly and through R & D policy.

(b) Employment policy has two main aspects: (i) the measures necessitated in the normal course of events by structural change; (ii) the specific measures imposed by the pervasive nature of the present technological revolution.

The diversified impact of technical change entails a permanent shift in the structure of employment which calls for a continuous flow of workers from contracting to expanding sectors. There is considerable scope for government action in this field. The first task is to foster the sectoral shifts in the labour force: besides disseminating appropriate information on labour market opportunities, the public

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50 In today's industrial societies the technological revolution could actually encompass manufacturing as a whole and half of the service sector, with the result that the technologically advanced share of the system accounts for about 70% of the private sector. The positive effect on employment stemming from the general increase in demand is thus confined to the remaining 30%

authorities must provide constant retraining skill development for the population.

If the above meaures are not sufficient to achieve full employment, the public authorities can attempt to reduce the overall labour supply by acting on two parameters: the share of the labour force in the total population and the share of working time in total time. As for the first parameter, they could lengthen the period of compulsory education, encourage people to take early retirement, promote part-time work, etc. The second parameter can be influenced by a reduction in annual working time, mainly through a reduction in weekly working hours. This has been happening for a long time: over the last two hundred years, we have moved from the 80-hour week (or more) common in the 19th century to the present 40-hour week.

The technological revolution in computer and information technologies adds a specific problem on account of its pervasive character. While in past long waves the technological revolution affected only some segments of industry, with no influence on services, the present technologies have also spread into this sector, which is no longer a reliable source of employment for those who have lost their jobs in industry. As my results show, when technological change is pervasive, the usual outcome is growth with a very low increase in or a stagnating level of employment, even for the long expansion phase of the long-wave. Considering that we are now in a situation of high unemployment, the employment prospects for the next decade could thus be very gloomy, and this makes it more necessary to devise ways of reducing total labour supply.

c) Finally, it is important to stress the importance of the equilibrium condition of the model, which links wage dynamics to average productivity growth in the system. This Keynesian component of Pasinetti's model is particularly important in the recovery phase of the long stagnation and becomes crucial in the long expansion because it is the way to provide the demand for a growing output.

APPENDIX 1

FURTHER ANALYTICAL ASPECTS OF PASINETTI'S MODEL OF STRUCTURAL CHANGE

In this appendix I first explain vertical integration, which is prerequisite for an understanding of Pasinetti's model, and then describe further analytical aspects of the model concerning the equilibrium conditions and the choice of techniques..

I. VERTICAL INTEGRATION[51]

1. Let us consider a closed economic system with no joint production[52] and treat fixed capital with the simplifying hypothesis of linear depreciation: in all industries a constant proportion d_j (j=1,2,...,m) of fixed capital drops out of the production process each year; of course, d_j could differ between industries.

The technology of the economic system is characterized by two elements :

(i) a row vector $\mathbf{a}_n$ (1x*m*) of direct labour requirements, and

(ii) a non-negative matrix $\mathbf{A}^{ST}$ (*m x m*), where each column *j* shows the amount of physical stock of fixed and circulating capital required to produce a physical unit of goods *i*. $\mathbf{A}^{ST}$ is the sum of two other matrices, one concerning the stocks of circulating capital ($\mathbf{A}^{C}$) and the other the fixed capital ($\mathbf{A}^{F}$) :

$$\mathbf{A}^{ST} = \mathbf{A}^{C} + \mathbf{A}^{F} \qquad (A.1)$$

To transform that into flows, let us define the diagonal matrix **D**, having the d_j on the principal diagonal, and a new *m x m* matrix $\mathbf{A}^{FL}$ of technical coefficients where, in place of fixed capital stock, there is the flow of depreciation :

$$\mathbf{A}^{FL} = \mathbf{A}^{C} + \mathbf{A}^{F}.\mathbf{D} \qquad (A.2)$$

To perform vertical integration, we start from the basic relations of the "open" Leontief model at year *t* (Pasinetti 1980, p. 19) :

$$\mathbf{X}(t) = \mathbf{A}^{FL}\,\mathbf{X}(t) + \mathbf{Y}(t) \qquad (A.3)$$

$$\mathbf{Y}(t) = (\mathbf{I} - \mathbf{A}^{FL})\,\mathbf{X}(t) \qquad (A.4)$$

$$L(t) = \mathbf{a}_n\,\mathbf{X}(t) \qquad (A.5)$$

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51 *I follow here Pasinetti (1973, 1986 a). For a discussion see Scazzieri (1990), Deprez (1990) and Pasinetti (1990)*

52 *This is also the assumption of national accounting when defining "branch" as opposed to "sector". In fact, the first concept refers to an homogeneous activity ("product"), which implies that the activities of multi-product enterprises are split into different branches. On the contrary, "sector" groups enterprises according to their main activity. Sectoral data are thus heterogeneous since they include not only joint products but also the other commodities produced or traded by the company alongside its main activity.*

$$\mathbf{S}(t) = \mathbf{A}^{ST}\,\mathbf{X}(t) \qquad \text{(A.6)}$$

where :

X(t) is the column vector of the physical quantities of the *m* commodities produced in year t;

Y(t) is the column vector of final demand (net product of the system), i.e. consumption **C**(t) plus investment $\mathbf{J}^{(d)}(t)$:
$\mathbf{Y}(t) = \mathbf{C}(t) + \mathbf{J}^{(d)}(t)$.

L(t) is total employment (scalar)

S(t) is the stock of capital goods at the beginning of year t.

2. The logical device of vertical integration singles out what Sraffa called a ***subsystem***, i.e. that part of an economic system formed by a "smaller self-replacing system the net product of which consists of only one kind of commodity" (Sraffa, 1960, p. 89). We thus compute what is directly and indirectly required, in the whole economic system, to obtain one physical quantity of final commodity *i*. Writing formula A.3 as :

$$\mathbf{X}(t) = (\mathbf{I} - \mathbf{A}^{FL})^{-1}\,\mathbf{Y}(t) \qquad \text{(A.7)}$$

a subsystem is just a column of the Leontief inverse matrix $(\mathbf{I} - \mathbf{A}^{FL})^{-1}$.

The subsystem *i* can also be determined for the total output of final commodity *i* ($Y_i(t)$, which is the *ith* component of vector **Y**(t)), instead of just for one physical unit of it. For this purpose, let us define the following magnitudes, which refer to what is required, in the whole economic system, to obtain quantity $Y_i(t)$:

$\mathbf{X}^{(i)}(t)$ is the column vector of the physical commodities to be produced;
$L^{(i)}$ is the quantity of labour (scalar);
$\mathbf{S}^{(i)}(t)$ is the column vector of the capital goods,

and let $\mathbf{Y}_i(t)$ be the column vector whose components are all zero except the *ith* one, which is Y_i. Then, the economic system (A.3) to (A.7) can be partitioned into *m* subsystems :

$$\mathbf{X}^{(i)}(t) = (\mathbf{I} - \mathbf{A}^{FL})^{-1}\,\mathbf{Y}_i(t) \qquad \text{(from A.7)} \qquad \text{(A.8)}$$

$$L^{(i)}(t) = \mathbf{a}_n\,(\mathbf{I} - \mathbf{A}^{FL})^{-1}\,\mathbf{Y}_i(t) \qquad \text{(from A.5 and A.7)} \qquad \text{(A.9)}$$

$$\mathbf{S}^{(i)}(t) = \mathbf{A}^{ST}\,(\mathbf{I} - \mathbf{A}^{FL})^{-1}\,\mathbf{Y}_i(t) \qquad \text{(from A.6 and A.7)} \qquad \text{(A.10)}$$

Putting

$$\mathbf{a}_n\,(\mathbf{I} - \mathbf{A}^{FL})^{-1} = \mathbf{v} \qquad \text{(A.11)}$$

$$\mathbf{A}^{ST}\,(\mathbf{I} - \mathbf{A}^{FL})^{-1} = \mathbf{H} \qquad \text{(A.12)}$$

equations (A.9) and (A.10) can be written in a more compact way :

$$L^{(i)} = \mathbf{v}\,\mathbf{Y}_i(t) \qquad \text{(A.9.1)}$$
$$\mathbf{S}^{(i)}(t) = \mathbf{H}\,\mathbf{Y}_i(t) \qquad \text{(A.10.1)}$$

The fact that subsystems (A.8) to (A.10) are another way of looking at the direct input-output relations (A.3) to (A.7) is proven by the fact that, summing the *m* vectors $\mathbf{X}^{(i)}$, $\mathbf{S}^{(i)}$ and $\mathbf{Y}_i$ as well as scalars $L^{(i)}$,we are back to the original magnitudes :

$$\Sigma_i \mathbf{X}^{(i)}(t) = \mathbf{X}(t); \qquad \Sigma_i \mathbf{S}^{(i)}(t) = \mathbf{S}(t)$$
$$\Sigma_i \mathbf{Y}_i(t) = \mathbf{Y}(t); \qquad \Sigma_i L^{(i)}(t) = L(t)$$

Equations (A.9.1) and (A.10.1) are particularly interesting. In fact, the first one shows "at a glance" the amount of direct and indirect labour incorporated in Y_i, while equation (A.10.1) shows the flow of commodities directly and indirectly required to replace the means of production used up for obtaining Y_i. Moreover, each column of matrix **H** gives the quantities of capital goods required, as stocks, in the whole economic system, to produce Y_i.

Pasinetti (1980, pp. 20-21; 1986) calls each component of vector **v** (v_i, i = 1,2,...m) a vertically integrated labour coefficient for commodity *i* and each column of matrix **H** ($\mathbf{h}_i$) *a unit of vertically integrated productive capacity* for commodity *i* .

3. A vertically integrated sector *i* operating at one unit of activity is represented by the elementary vector :

$$[1 \quad 1 \quad v_i] \qquad (i = 1,2,...m) \qquad (A.13)$$

where the first component refers to final commodity *i*, the second component to the vertically integrated productive capacity for *i* and the third component to the vertically integrated quantity of labour for *i*.

The vertically integrated *productive capacity* (hereinafter "productive capacity"), which is represented in a simple way by 1 in vector (A.13), is a composite commodity whose elements are found in a column of matrix **H**. The productive capacity is thus a set of different types of physical goods taken in strictly defined proportions.

II. THE EQUILIBRIUM CONDITIONS

1 The fact that the system is growing requires a corresponding increase in the stock of capital, which means that condition (II.6) becomes :

$$\frac{d}{dt}[K_i(t)] = \frac{d}{dt}[X_i(t)] \qquad i = 1,2,...(n-1) \qquad (A.14)$$

In term of flows, this increase in capital stock is reflected in an increase in the output of sector k_i (X_{k_i}) due to new investment. In fact, at any period *t*, gross investment is equal to the sum of the replacements of the worn-out capacity $[(1/T_i)a_{in}X_n]$ and new investment $[a_{k_in}X_n]$. Indicating these two elements respectively by X'_{k_i} and X''_{k_i}, our definition is written :

$$X_{k_i}(t) = X'_{k_i} + X''_{k_i}(t) \qquad (A.15)$$

X''_{k_i} grows for two reasons: because of the additions to the productive capacity for final sector *i* and because of new investments in sector k_i to provide the capital goods required by the expansion of sector *i*. Thus :

$$X''_{k_i}(t) = \frac{d}{dt}\left[X_i(t) + \gamma_i X_{k_i}(t)\right] \qquad \text{(A.16)}$$

Taking into consideration formula (II.12) and the evolution over time of a_{nk_i}, a_{in} and $a_{k_i n}$, formula (A.16) becomes :

$$a_{k_i n}(0)e^{r_i t}X_n(0)e^{gt} =$$

$$\frac{d}{dt}\left\{a_{in}(0)e^{r_i t}X_n(0)e^{gt} + \gamma_i C1_i\left[a_{k_i n}(0)e^{r_i t} + \frac{1}{T_i}a_{in}(0)e^{r_i t}\right]X_n(0)e^{gt}\right\}$$ [53]

When calculating the derivative we should bear in mind that r_i is not constant over time but rather $r_i = f(t)$. Simplifying by $X_n(0)\, e^{(r_i + g)t}$, we have :

$$a_{k_i n}(0) = (r_i' t + r_i + g)\, \{a_{in}(0) + \gamma_i C1_i\, [a_{k_i n}(0) + \frac{1}{T_i}\, a_{in}(0)]\}$$

Solving with respect to $a_{k_i n}$, we obtain :

$$a_{k_i n}(0) = (r_i' t + r_i + g)\, a_{in}(0)\, \frac{\gamma_i T_{k_i} + T_i(T_{k_i} - \gamma_i)}{T_i(T_{k_i} - \gamma_i - (r_i' t + r_i + g)\gamma_i T_{k_i})}$$ [54]

Since this relation is valid for any period *t* (and not only for the initial period), the equilibrium condition for the accumulation of capital is in general :

$$a_{k_i n} = (r_i' t + r_i + g)\, a_{in}\, \frac{\gamma_i T_{k_i} + T_i(T_{k_i} - \gamma_i)}{T_i(T_{k_i} - \gamma_i - (r_i' t + r_i + g)\gamma_i T_{k_i})} \qquad \text{(A.17)}$$

The term $(r_i' t + r_i)$ is indeed the instantaneous percentage rate of change of demand with respect to the previous period. In fact:

$$\frac{d a_{in}/dt}{a_{in}} = r_i' t + r_i = \dot{r}_i$$

Substituting this last result into formula (A.17), we eventually have:

$$a_{k_i n} = (\dot{r}_i + g)\, a_{in}\, \frac{\gamma_i T_{k_i} + T_i(T_{k_i} - \gamma_i)}{T_i(T_{k_i} - \gamma_i - (\dot{r}_i + g)\gamma_i T_{k_i})} \qquad \text{(A.18)}$$

Formula (A.18) tells us that, in each sector, new investments *per capita* should bear a precise relationship to the consumption coefficient for that sector. This relationship is

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53 *Constant $C1_i$ was defined in paragraph II.2.5 as $C1_i = T_{ki}/(T_{ki} - \gamma_i)$.*

54 *Note that this result differs from Pasinetti's (Pasinetti 1981 p.53, footnote 2, case in which $r_i = 0$).*

determined by the growth rate of demand for final commodity *i* and by the technical coefficients T_{k_i}, T_i and γ_i. The new investments needed for equilibrium in sector *i* are obtained by multiplying formula (A.18) by $X_n(t)$:

$$X''(t) = D1_i\,(\dot{r}_i + g)\,a_{in}\,X_n(t) \qquad \text{(A.19)}$$

$$\text{where } D1_i = \frac{\gamma_i T_{k_i} + T_i(T_{k_i} - \gamma_i)}{T_i(T_{k_i} - \gamma_i - (\dot{r}_i + g)\gamma_i T_{k_i})}$$

This equilibrium value for new investments (formula (A.19)) entails a modification in the replacements of worn-out capacity. Incorporating formula (A.19) into formula (A.15) and solving with respect to X'_{k_i}, we obtain :

$$X'_{k_i} = D2_i\ \ a_{in}\,X_n(t) \qquad \text{(A.20)}$$

$$\text{where } D2_i = \frac{T_{k_i}\left[1-\left(\dot{r}_i + g\right)\gamma_i\right] + \left(\dot{r}_i + g\right)T_i}{T_i\left[T_{k_i} - \gamma_i - \left(\dot{r}_i + g\right)\gamma_i T_{k_i}\right]}$$ [55]

Finally, the above equilibrium conditions permit to obtain a further specification of the solution for physical quantities (formula (II.12)). At this point, it is sufficient to introduce in formula (II.12) the equilibrium value of a_{k_in} (formula (A.18)) or, alternatively, to rely on formula (A.15) while taking into consideration formulae (A.19) and (A.20). The result we obtain is the following :

$$X_{k_i} = (\dot{r}_i + g + \frac{1}{T_i})\ D3_i\ \ a_{in}\ \ X_n \qquad \text{(A.21)}$$

$$\text{where } D3_i = \frac{T_{k_i}}{T_{k_i} - \gamma_i - (\dot{r}_i + g)\ \gamma_i\ \ T_{k_i}}$$

2. If we take into account the changes over time in demand and population and the equilibrium condition for capital accumulation, this complicates somewhat the macroeconomic condition for full employment.

Let us start by substituting in formula (II.33) the value for a_{k_in} given by formula (A.18) and collect $a_{in}\,a_{k_in}$:

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55 *This result corresponds to Pasinetti's (Pasinetti, 1981, p. 53, footnote 2) only when* $T_{k_i} = T_i$.

$$\sum_i a_{ni}\, a_{in} + \sum_i Cl_i \left[Dl_i(\dot{r}_i \quad + g) + \frac{1}{T_i} \right] a_{in} \quad a_{k_i n} = \; 1$$

However, if we wish to express the above condition by abandoning the hypothesis that the total labour force equals the total population (formula (II.34)), we should adjust the technical coefficients to make them comparable with the demand coefficients. In fact, the consumption coefficients a_{in} refer to annual *per capita* consumption while the technical coefficients refer to that fraction of the year which corresponds to the actual working time. To make them homogenous, we have simply to divide the latter by $\mu\nu$; the previous formula then becomes :

$$(1/\mu\nu)\sum_i a_{ni}\, a_{in} + (1/\mu\nu)\sum_i Cl_i \left[Dl_i(\dot{r}_i \quad + g) + \frac{1}{T_i} \right] a_{in} \quad a_{k_i n} \; = \; 1 \qquad (A.22)$$

Finally, if we introduce into formula (A.22) the changes over time in the technical coefficients, we obtain :

$$(1/\mu\nu)\sum_i a_{ni}(0)\, a_{in}(0) e^{(r_i-\rho_i)t} + (1/\mu\nu)\sum_i Cl_i \left[Dl_i(\dot{r}_i + g) + \frac{1}{T_i} \right] a_{in}(0) a_{k_i n}(0)\, e^{(r_i-\rho_{k_i})t} = 1$$

(A.23)

III. THE CHOICE OF TECHNIQUES

1. When several techniques are available to produce one unit of the same commodity, the criterion usually adopted in economic theory is that the technique which minimizes the cost of production will be chosen. Indicating by the index 1,2,..., z the different technical methods to obtain the physical quantity of commodity X_i (**i** = 1,2,...,n-1), we can write :

$$\overline{X_i} = f_i^{(1)}\left(\mathbf{K}_i^{(1)}, x_{ni}^{(1)}\right)$$

$$\vdots \qquad\qquad\qquad\qquad (A.24)$$

$$\overline{X_i} = f_i^{(z)}\left(\mathbf{K}_i^{(z)}, x_{ni}^{(z)}\right)$$

where $\mathbf{K}_i^{(k)}$ (k = *1,2,...z*) is the vector of the physical inputs of machines and intermediate commodities required in the vertically integrated sector *i*

$x_{ni}^{(k)}$ (k = *1,2, ...z*) is the scalar of the quantity of direct labour required in the same vertically integrated sector.

If $\mathbf{p}_{k_i}^{(k)}$ (for k = *1,...,z*) are the vectors of the prices of inputs $\mathbf{K}_i^{(k)}$ required by the z alternative techniques, and if w is the wage rate, the choice of techniques consists in the following minimization problems :

$$\text{Min}\begin{cases} \mathbf{p}_{k_i}^{(1)}\mathbf{K}_i^{(1)}+x_{ni}^{(1)}\ w \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \mathbf{p}_{k_i}^{(z)}\mathbf{K}_i^{(z)}+x_{ni}^{(z)}\ w \end{cases} \tag{A.25}$$

Formula (A.25) is the *choice of technique function* (Pasinetti 1981, p. 190). All its elements are additive and each one of them is simply the product of a price ($\mathbf{p}_{k_i}$ or w) by a physical quantity ($\mathbf{K}_i$ or x_{ni}). To understand what determines the choice of a particular technique let us recall the price equations.

2. Performing vertical integration we obtained the following remarkable result (formula II.15):

$$p_{k_i} = \left[\frac{T_{k_i}}{T_{k_i} - \gamma_i - \pi\gamma_i T_{k_i}} a_{nk_i}\right] w \tag{II.15}$$

The price of any capital good is thus made up of two components: the term in brackets, concerning the technical coefficients (a_{nk_i}; T_{k_i}; γ_i), and the rate of profit (π), multiplied by the wage rate[56]. Thus, any change in the wage rate is immediately reflected in prices via the proportionality factor within brackets. This has a fundamental implication for the choice of technique, because *it makes it independent from the wage rate*.

If wage increases are uniformly and instantaneously spread over all sectors, this wage increase will proportionally change all prices of capital goods in the choice of technique function (A.25). The cost of each technique will of course increase, but this will not alter the ranking of the different techniques with respect to their cost. For instance, if we dispose of 10 techniques for producing final commodity *i* and, at a given level of the wage rate technique n. 7 is the cheapest, it will remain the cheapest when the wage rate is multiplied by 1000. We should thus revise the conventional interpretation of the two long term trends: increasing mechanization and the growth of the real wage rate. Usually these facts are interpreted as a process of substitution of capital for labour determined by a change of the "factor prices". We have seen, however, that is is not the case: the rate of profit can remain unchanged while the degree of mechanization steadily increases. "The wage rate will also increase, but as an effect [the link with productivity], not a cause of technical change!" (Pasinetti 1981, p.216).

These results also show the need to be careful when interpreting some facts. As Pasinetti (1981, p.216) points out, if we notice that in a final sector the increasing wage (which

56 *This is the particular form taken by a more general result. In fact, vertical integration allows to show that the price of any commodity (be it final, intermediate or capital good) is ultimately made up by only two components : wages and profits. See Pasinetti (1973, p 22) for the competitive case and Reati (1986, p.39) for the non-competitive market structures case.*

reflects the general increase of productivity) is accompanied by the substitution of some workers with a machine, we should not conclude that this is due to the wage increase. Indeed, the wage has risen also in the capital goods sector. The substitution of labour by the machine is thus dependent on another factor, such as productivity growth in the machine producing industry, so that the cost of the machine has increased less than the wage rate.

3 The above result of the independence of the choice of technique from the wage rate also holds in the case of an open economy, provided that we allow for flexible exchange rates.

Let us consider the case of two trading countries: in country A the wage rate increases while in country B it remains stable. The machines produced in B will thus become cheaper than those produced in A and this will influence the choice of the technique in A, in favour of a more capital intensive technique using machines imported from B.

However, this is only a short term phenomenon. In fact, the wage increases in A will entail a loss of competitivity and a corresponding depreciation of its currency; the increased cost of foreign machines that results will reestablish the initial situation[57].

4. Formula (II.15) above shows that, for the choice of techniques, there is an asymmetry between wages and profits. If the wage rate does not influence the choice of the technique, for the rate of profit the situation is different : since it belongs to the term within brackets, it cannot be separated from technology. This is because the profit component of each price comes from the product of the rate of profit and the indirect part of total labour requirements (term $\pi \gamma_i T_{k_i}$ in formula II.15). And since the degree of capital intensity of production (the proportion of direct to indirect labour) is usually different from one technique to another, any change in the rate of profit will affect the cost of the alternative methods in a different way, thus influencing the choice of technique.

Recalling the well-known inverse relation between profit and wage rates, one could object that what has just been said is an implicit recognition that the choice of technique is indeed determined by the wage rate, via its influence on the rate of profit. In general this is not true.

In fact, the profit rate is inversely related to the wage rate only when it is not possible to translate into prices the cost increases. Now, in Pasinetti's model, the rate of profit remains constant just because the wage increases are transferred into prices. The mechanism was already outlined in section 2: there is, first, the productivity growth pushing down unit costs; on the other hand, the wage rate increases in line with productivity (possibly at the *"standard"* rate, to keep the general price level stable) and this will (fully or partially) compensate the productivity effect on price, without any modification in the rate of profit.

The profit rate is squeezed only when the wage increases more than productivity *and, at the same time*, it is not possible to transfer it into prices[58]. It is only in this case that, by reducing the rate of profit, wage increases indirectly influence the choice of technique.

However, even in this case it is not possible to say that, in general, a reduction in the rate of profit will lead to the adoption of a more capital-intensive technique. In fact, a change in the rate of profit *will change the entire structure of prices* (Pasinetti 1977, pp. 82-84), and it is not at all certain that, within the new price structure, the cost minimizing technique will be

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57 *The author thanks D. Todd for drawing his attention on this point.*

58 *A typical reason for this impossibility is the strength of international competition . Another reason could be a deliberate policy to avoid inflation.*

more capital intensive: the outcome is *a priori* indeterminate. This is confirmed by Sraffa's (1960) contribution on the "switching of techniques". As this author has shown, the irregular shape of the wage-profit curve implies that a capital intensive technique, which is adopted at a low level of the rate of profit and then abandoned in favour of a less capital-intensive technique when the rate of profit increases, can become profitable again when the rate of profit is further increased (see Pasinetti 1977, chapter VI, and Harcourt 1972 for an extensive discussion of the topic)

Appendix 2

An example of the passage from the individual productivity level (α_{ji}) to the productivity of the sector (α_i)

(logistic diffusion ; trend 1% per year; $\Delta_i = 0.3$; the productivity levels are indices)

years	D(t)	α_{tr}	α_{ii}															α_i
0	0.522	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1	1.046	101.01	131.31	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.01	101.32
2	2.084	102.02	132.63	132.63	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.02	102.66
3	4.109	103.05	133.96	133.96	133.96	103.05	103.05	103.05	103.05	103.05	103.05	103.05	103.05	103.05	103.05	103.05	103.05	104.32
4	7.944	104.08	135.31	135.31	135.31	135.31	104.08	104.08	104.08	104.08	104.08	104.08	104.08	104.08	104.08	104.08	104.08	106.56
5	14.805	105.13	136.67	136.67	136.67	136.67	136.67	105.13	105.13	105.13	105.13	105.13	105.13	105.13	105.13	105.13	105.13	109.80
6	25.923	106.18	138.04	138.04	138.04	138.04	138.04	138.04	106.18	106.18	106.18	106.18	106.18	106.18	106.18	106.18	106.18	114.44
7	41.338	107.25	139.43	139.43	139.43	139.43	139.43	139.43	139.43	107.25	107.25	107.25	107.25	107.25	107.25	107.25	107.25	120.55
8	58.662	108.33	140.83	140.83	140.83	140.83	140.83	140.83	140.83	140.83	108.33	108.33	108.33	108.33	108.33	108.33	108.33	127.39
9	74.077	109.42	142.24	142.24	142.24	142.24	142.24	142.24	142.24	142.24	142.24	109.42	109.42	109.42	109.42	109.42	109.42	133.73
10	85.195	110.52	143.67	143.67	143.67	143.67	143.67	143.67	143.67	143.67	143.67	143.67	110.52	110.52	110.52	110.52	110.52	138.76
11	92.056	111.63	145.12	145.12	145.12	145.12	145.12	145.12	145.12	145.12	145.12	145.12	145.12	111.63	111.63	111.63	111.63	142.46
12	95.891	112.75	146.57	146.57	146.57	146.57	146.57	146.57	146.57	146.57	146.57	146.57	146.57	146.57	112.75	112.75	112.75	145.18
13	97.916	113.88	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	148.05	113.88	113.88	147.34
14	98.954	115.03	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	149.54	115.03	149.17
15	100.000	116.18	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04	151.04

To make this table more explicit, let us write formula (IV.2) as follows: $\alpha_i(t) = \alpha_i(0)\ [(1 - D(t)) + (1 + \Delta_i)\ D(t)]\ e^{\sigma\ t}$. We see that the productivity of the sector (α_i) is the sum of two elements: the productivity of the innovators, weighted with the diffusion function: $\alpha_i(0)\ e^{\sigma\ t}\ [(1 + \Delta i)\ D(t)]$, and the productivity of the other enterprises: $\alpha_i(0)\ e^{\sigma\ t}\ [(1 - D(t)]$. Consider, for instance, the sixth year. According to the diffusion function, 25.9% of total output is obtained with the new technique, and 74.1% with the old one. The productivity of the first segment of the sector is: $138.04 \cdot ,0.259 = 35.76$; the productivity of the second is: $106.18 \cdot 0.741 = 78.68$. The productivity of the sector is: $35.76 + 78.68 = 114.44$. The columns of the table show the productivity index of the individual innovators.

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