MICRO AND MACRO DYNAMICS: INDUSTRY LIFE CYCLES, INTER-SECTOR COORDINATION, CO-EVOLUTION AND AGGREGATE GROWTH.

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INTRODUCTION.

The present paper focuses on the effects of micro- and industry-economic phenomena, such as the industry life cycle (ILC), inter-sector coordination and the co-evolution of technologies and institutions, on macro economic growth patterns. The analysis is based on a model of economic development by the creation of new sectors that we previously developed (Saviotti, Pyka, 2004a, 2004b, 2004c). In this paper we use the model in a modified version, including a new demand function. Furthermore, the financial availability term is specified in more detail. In what follows we first give a brief description of the model and then present the work which constitutes the specific focus of this paper.

1) A MODEL OF ECONOMIC DEVELOPMENT BY THE CREATION OF NEW SECTORS.

In this model each new sector is created by an important innovation, which gives rise to a new product, which is in general highly differentiated. A sector is here defined as the population of firms producing this highly differentiated product. The sector is initiated by the first entrepreneur that begins to produce the new product. The entrepreneur is induced to do so by the expectation of the temporary monopoly that he/she will have before imitation begins. However, if the new product is successful, imitation will take place, gradually raising the intensity of competition within the sector and eroding the monopolistic extra profits. As further imitation and entry occurs the intensity of competition will rise, reaching values comparable to those of mature sectors, thus transforming an innovating sector into a routine of the economic system. In Schumpeterian terms, the sector will cease to be innovating and will become part of the circular flow.
Competition plays a very important role in this model both because the expectation of temporary monopoly induces entrepreneurs to enter and because we distinguish intra from inter sector competition. Inter-sector competition exists because the outputs of different sectors can sometimes provide comparable services.

In the model each sector is represented by an equation describing the entry and exit of new firms. Entry is determined by the size of the potential market, as measured by the adjustment gap, and by financial availability. Exit is determined by the increasing intensity of competition and by mergers and acquisitions. As a result of the basic hypotheses on competition and on demand each industrial sector follows a life cycle, with the number of firms increasing first, reaching a maximum, and then falling towards an oligopoly. In our model this cyclic behaviour is stable under a wide, but not infinite, range of conditions. In each sector employment follows a path very similar to that of the number of firms, increasing at first and subsequently falling after having reached a maximum. In past work we showed how an adequate inter sector coordination can give rise to a stable macroeconomic employment growth path even when each sector provides declining employment.

1.1) BACKGROUND TO THE MODEL

The basic features of the model will be briefly summarised here, but a more extended description can be found in Saviotti, Pyka (2004a, 2004b, 2004c). Our economic system is constituted by a variable number of industrial sectors, each sector being defined as the set of firms producing a unique but differentiated output. Our analysis is in principle applicable to the production of services, but in what follows we will refer mainly to the production of products. One very specific feature of our model is the endogenous creation of new sectors. In other words, the intrinsic mechanisms of development of our economic system lead to the creation of new sectors, or alternatively, the development of the system is not sustainable unless new sectors are created.

Each sector is created by an innovation which gives rise to an adjustment gap, a variable intended to capture the size of the potential market established by the innovation. However, this market is initially empty because neither the production capacity nor a structured demand for the new product exists. Both the production capacity and the evolution of the demand will take place during a (possibly long) period of time, by means of a gradual interaction of producers and users. Thus, the adjustment gap measures the extent to which the market is far
from saturation. When the market becomes saturated the adjustment gap is reduced to zero. The adjustment gap is very large right after the creation of the sector, and later it decreases gradually, although not at all times. It is in fact possible for the adjustment gap to grow during certain periods if innovations following the one creating the sector improve either the performance of the product or the efficiency with which it is produced, or both. In our model search activities affect both the maximum possible demand ($D_{\text{max},i}$) and the instant demand ($D_i$) in a sector. If we consider that analytically the adjustment gap (fig. 1c) is defined as the difference between these two types of demand, we can understand that the time path of the adjustment gap depends on the those of $D_{\text{max},i}$ (fig 1b) and of $D_i$ (fig. 1a) During particular periods it is possible for $D_{\text{max},i}$ to grow more rapidly than $D_i$, thus enlarging the adjustment gap, or delaying the saturation of the market. In the long run we expect the adjustment gap to be reduced to zero, or the market to become saturated.

Each sector is actually created by an entrepreneur who establishes a niche induced by the expectation of a temporary monopoly. If the innovation is successful imitative entry takes place leading to the creation of a market. During this process imitative entry gradually raises the intensity of competition, thus reducing the inducement to further entry. Competition plays a very important role in our model, in two different senses. First, by its absence (temporary monopoly) it provides the inducement for the first entrepreneur to create a niche. Later the gradually increasing intensity of competition due to imitative entry gradually reduces the inducement to further entry. Second, in our model we distinguish two components of competition, intra- and inter-sector competition. Intra-sector refers to the competition of firms
within a given sector, while the existence of inter sector competition depends on the possibility that different sectors provide comparable services.

The combination of a gradually increasing intensity of competition and of market saturation transforms what was initially an innovative sector into a mature one. To use a Schumpeterian metaphor, a new sector is created as an innovative one and merges later into the circular flow, the set of existing routines of the economic system (Schumpeter, 1912, 1934). Our model is thus very Schumpeterian in character for the following features:

(i) a sector is created by an entrepreneur induced by the expectation of a temporary monopoly;
(ii) if the innovation is successful a bandwagon of imitators enters, eroding and gradually abolishing the initial temporary monopoly;
(iii) in the whole process the initially innovative sector is transformed into a routine and becomes part of the 'circular flow'.

However, a number of other authors have influenced our model. A central preoccupation of ours has been the effects of and the inducements for the changing composition of the economic system. We find that this preoccupation is not sufficiently present in most models of economic growth developed in the past. Some recent models of growth begin to include a representation of the composition of the economic system, although in ways that we do not find completely adequate. For example Romer (1987, 1990) considers the creation of sectors producing new types of capital goods as the logical outcome of the activities of research and development. In his model these new sectors are added to the previous ones. In Aghion and Howitt (1998) the composition of the system changes due to the innovations created by R&D, but new innovations can substitute old ones. In both cases the direction in which the composition of the economic system is going to change is not clear. We are assuming that the output variety of our economic system increases in the course of time and that this increase is a necessary requirement for the continuation of long term growth. Thus, although some old products and technologies may be displaced by new innovations, more new ones will be added either by radical innovations or by the specialisation of pre-existing products. The emphasis we place on the changing composition of the economic system relates closely our model to the literature on structural change and economic development, for example to the work of Salter (1960), Cornwall (1977), Pasinetti (1981, 1993), Fagerberg (2000) Fagerberg, Verspagen (1999, 2002), Verspagen (1993,2002) and more recently to Metcalfe et al (2005).

On the other hand, the role played by the emergence of new products relates our model to
those of Stokey (1988, 1991), Grossman and Helpman (1991a, 1991b). We find inspiration in the work of all these authors, but we depart from most of these for a number of assumptions, such as the role played by variety and by equilibrium. Here we agree with Schumpeter that even if the economic system were to start in a position of equilibrium, innovations would perturb this equilibrium. In presence of a constant stream of innovations the system would most of the time be in a steady state which, while ordered and showing the invariance of some state properties, is not equivalent to the equilibrium of a conservative system but rather to the steady states of dissipative systems (Nicolis Prigogine, 1989).

A feature of our model is that increasing efficiency is not the only factor driving economic growth. On the contrary, we think that increasing efficiency in pre-existing sectors and the increasing variety created by the emergence of new sectors are two complementary trends in economic development. Both of these trends are required if economic development is to proceed. We call the trend towards growing variety the creativity of the economic system. Thus, we can reformulate our previous statement by saying that efficiency growth and variety growth are two complementary trends in economic development (Saviotti, 1996). Without creativity the system would have a constant composition and it would run into a bottleneck by becoming able to produce all the demanded output with a declining proportion of the resources required (for a similar point of view see Pasinetti, 1981). Without efficiency the resources required for search activities, and thus for the creation of innovations, could not be found. Furthermore, the growing efficiency of new sectors after they have been created allows these new sectors to acquire their 'economic weight', that is the market size that only becomes available when the prices of new products fall substantially and their performance increases.

1.2) THE STRUCTURE OF THE MODEL.

The central feature of our model is a system of equations, one for each sector, which specifies how the number of firms in the sector changes following entry and exit (Eq. 1). Entry is determined by the size of the adjustment gap, that is of the potential market created by the innovation, and by financial availability FA_{it}. FA_{it} is not just the quantity of money available in the economic system, but measures the amount of resources the economic system is prepared to allocate to a new and unknown sector. Thus, FA_{it} depends both on resources and on the availability of institutions that can appropriately evaluate the potential of new sectors, often created by radical innovations. In the very early phases of an innovation the knowledge required to assess its economic prospects is likely to be in very short supply, possibly being all tied up in the creation of the innovation itself. In these conditions new institutions may be
required to assess the potential of innovations. Furthermore, changing conditions during the process of economic development may induce financial innovations adapted to these changes. Venture capital firms and business angels are just examples of financial innovations, but many others emerged during the course of economic development (Perez, 2002). In summary, FA$^i_1$ includes both the availability of resources and complementary institutional innovations in finance. Financial availability can be considered as a particular instance of co-evolution of technologies and institutions.

$$N^{i+1}_j - N^i_j = k_i \cdot FA^i_j \cdot AG^i_j - IC^i_j - MA^i_j$$  \hspace{1cm} (1)

Exit from a sector is determined by increasing intensity of competition and by mergers and acquisitions. As previously pointed out, the inducement to enter a new sector decreases as the intensity of competition rises as a result of imitative entry starting from the initial situation of temporary monopoly enjoyed by the first entrepreneur. Eventually no further entry will take place and exit will begin. Any process that reduces the number of firms in the sector contributes to exit. Although the term is called MA$^i_1$, for mergers and acquisitions, it can include failures because they are determined by the same factors.

1.2.1) DEMAND

In the previous versions of our model (Saviotti, Pyka, 2004a, 2004b, 2004c) we had a very simplified representation of demand. Essentially demand entered the model in two ways: first, by means of the concept of adjustment gap (AG$^i_1$), defined equal to the difference between the maximum and the actual demand at a given time; second, by means of the assumption that all output produced in the economy was going to be consumed. The second assumption is equivalent to Say's law. Those assumptions were included in the model in order to simplify it. Of course, they were very restrictive and limited unnecessarily the model. In the present version we introduced the following demand form:

$$D^i_j = \frac{\bar{Y}^i_j \cdot \Delta Y^i_j}{p^i_j}$$  \hspace{1cm} (2)

where $Y^i_j$, $\Delta Y^i_j$ and $p^i_j$ are the average value of the services produced, the degree of differentiation and the average price of the products of sector i respectively. In this section we describe the explorations of this demand function that we carried out. In order to explain how these experiments were carried out we have to give the time dependence of $Y^i_j$, $\Delta Y^i_j$ and $p^i_j$ (Eqs 3, 4, 5 and fig. 2 a, b, c).
where SE$_i^t$ are the search activities carried out in sector i, k$_{14}$-k$_{19}$ are constants, to be considered as parameters affecting the time paths of $Y^t_i$, $\Delta Y^t_i$ and $p^t_i$. Equations (4) and (5) have the form of logistic equations. They tell us that both the services performed by the products of sector i and their degree of differentiation rise with search activities at a rate which starts being very slow, accelerates until reaching a maximum and then falls gradually. This assumption is not completely ad-hoc. The logistic form of the equation can be obtained by assuming that (i) $Y^t_i$ has an upper boundary, and that (ii) the rate of growth of $Y^t_i$ depends on the product of its instant value times the difference between its upper boundary and its instant value. In turn, these assumptions are equivalent to admitting that improvements in the performance of a new technology can be very fast and even accelerate in the initial period of its lifecycle, when learning effects etc. can provide a source of increasing returns to adoption, but that eventually decreasing returns to further improvements will be encountered, leading to an upper boundary. The constants k$_{14}$ and k$_{16}$ give us the time when the logistic curve starts growing, while the constants k$_{15}$ and k$_{17}$ give us the slope of the central part of the curve, during which the rate of growth of either $Y^t_i$ or $\Delta Y^t_i$ reaches a maximum. Varying k$_{14}$-k$_{17}$ we can vary the rate of growth of $Y^t_i$ and $\Delta Y^t_i$. Using these forms for $Y^t_i$ and $\Delta Y^t_i$ we assume that both the services produced and the degree of differentiation of the products of sector i will increase as a consequence of search activities. The rate of growth of $Y^t_i$ and $\Delta Y^t_i$ will start being very slow, will accelerate later but in the end it will slow down due to the exhaustion of
the possibilities inherent in the technology used to modify $Y^i$ and $\Delta Y^i$. The equation for $p^i$ has a different form because we expect $p^i$ to fall as a result of search activities.
2) MODEL RESULTS

2.1) BASIC MODEL RESULTS

In this section we present what we consider to be the most basic results of the model. Within a wide range of conditions the number of firms in each sector grows initially, reaches a maximum and then falls to a fairly low value (Fig. 3). Within these conditions each sector seems to follow a life cycle, similar to the ones detected by Klepper (1996), Jovanovic and MacDonald (1984), Utterback and Suarez (1993). However, in our model this industry life cycle (ILC) is created by variables very different from those used by the previous authors in their models and including increasing returns to R&D, radical innovations or the emergence of dominant designs. In our case the cyclical behaviour is caused only by the combined dynamics of competition and of market saturation. We do not wish to say that cyclical behaviour cannot arise under the conditions identified by the previous authors. We simply wish to say that cyclical behaviour can arise also from the interplay of competition and of market saturation. As in the previous models, we call the time at which the number of firms in a sector reaches a maximum the shake-off.

Fig. 3) Time path of the number of firms created in each sector during the process of economic development.

The adjustment gap can start falling immediately after the emergence of a new sector, or it can increase for a while as a result of technological progress, but in the end it will fall to a low or zero value (Fig. 4).
Fig. 4) Time paths of the adjustment gaps of different sectors.

The intensity of competition (fig. 5) within each sector rises during the initial period of fast entry, reaches a maximum and then falls. However, the presence of inter-sector competition prevents the intensity of competition of each sector from falling to very low or zero values as a consequence of the growing industrial concentration after the shake-out.

Fig. 5) Time path of the intensity of competition.

Starting from the behaviour of microeconomic variables, such as the previously described ones, we can calculate the curves for aggregate variables. Fig. 6 shows the time path of aggregate employment, obtained by aggregating the employment curves of individual sectors.
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The time path of demand can be modified by varying the parameters affecting the variables contained in the demand function (see Eqs. 2, 3, 4, 5). Demand dynamics can be expected to affect $D_{\text{max},i}$ and $D_{i}$ and thus the adjustment gap $AG_{i}$, which is by definition equal to $D_{\text{max},i} - D_{i}$. In turn, $AG_{i}$ can be expected to affect the shape of the industry life cycle (ILC) and as a consequence macroeconomic development paths. To explore fully the parameter space of the variables that can potentially affect macro-economic development paths is very time consuming and we have not yet been able to do so. Thus, here we present the results of two similar experiments, a more systematic but as yet incomplete one, consisting of varying the parameters affecting the components of the demand function, and a more approximate one, in which we assume that a variables percentage of each given market remains unsaturated.

The figures in table 1 display the results of the first experiment. They show that changes in demand parameters affect the shape of the ILC and indirectly the aggregate employment growth path.
Table 1: Demand experiments
Fig. 7) Effect of changing demand by means of $Y_i$ on the linearized slope of the employment growth path.

The figures in table 1 and fig. 7 show that raising the rate of growth of services ($Y_i$) creates a larger number of firms, increases the rate of growth of employment and reduces the fluctuations in the aggregate employment growth path while slightly depressing the average level of employment in the early phases of economic development. Quite apart from its detailed results this experiment shows that a change in a microeconomic variable (a component of demand) affects the shape of the industry life cycle of each sector and as a consequence the aggregate employment growth path.

In the previous experiments we varied a component of demand, the rate of growth of services $Y_i$. The other components of demand, product differentiation ($\Delta Y_i$) and price ($p_i$) can also affect the shape of the ILC and indirectly aggregate growth paths. The combined influence of $Y_i$, $\Delta Y_i$ and $p_i$ on the shape of the ILC can give rise to very complicated aggregate paths. The complete analysis of the space of all the parameters potentially affecting the shape of the ILC can be very time consuming. To simplify the situation we carried out an approximate procedure of which the systematic variation of several parameters constitutes a more general analogue. However, such results are interesting because they tell us in a very simple way what types of change we can expect in the shape of the ILC and even in what conditions the ILC itself might stop occurring. We studied the influence of market saturation on the shape of the ILC by assuming that a given fraction of the market does not saturate and by varying such fraction in subsequent experiments. The results we obtained show that the higher the fraction
of the market which remains unsaturated, the longer the tail of the ILC and the longer its life span. Furthermore, the very same nature of the ILC is affected by the incomplete saturation of markets. As the unsaturated fraction of the market grows, not only the tail of the ILC grows, but the number of firms can start increasing after having declined. In other words, the very same phenomenon of the ILC is intrinsically related to market saturation. The macroeconomic implications of these results are clear: when market saturation is complete output and employment fluctuate considerably, while as the fraction of markets remaining unsaturated increases output and employment grow more rapidly and with more reduced fluctuations. Of course, it might be objected that in the end markets will saturate, and that the situation we invoke is artificial. However, the procedure used in this case could be considered an approximation for the systematic change of the rate of market saturation. The results of this set of experiments could then be summarized as follows: when the rate of saturation of market \( i \) slows down, the tail of the curve \( (N_i^t) \) (time path of the number of firms in sector \( i \)) becomes longer and longer and correspondingly the rate of growth of industrial concentration slower and slower.

2.3) INTER-SECTOR COORDINATION AND MACROECONOMIC TRENDS.

In this section we are interested in investigating the effect of inter-sector coordination on macroeconomic growth paths. Inter-sector coordination can be measured by the delay between the creation of sector \( n \) and that of sector \( (n+1) \). With an adequate inter-sector coordination the growing employment creating capacity of sector \( (n+1) \) can be expected to compensate for the falling capacity of sector \( n \). However, we can expect a long delay between sectors \( n \) and \( (n+1) \) to hinder the process of compensation, with employment falling in sector \( n \) before it recovers due to the influence of sector \( (n+1) \). This process will interact with the duration of the ILC, since when there is a ‘long’ ILC in sector \( n \), macro economic stability will be more tolerant of a delay in the creation of sector \( (n+1) \). In principle the factors that influence the shape and duration of the ILC can be expected to interact with the inter-sector delay. Studying the joint influences of the factors affecting the ILC and of inter sector delays should enable us to derive the most favourable conditions for the emergence of a sustainable macro-economic growth path. We can expect that the shorter are ILCs the faster the economic system will have to create new sectors in order to provide a balanced growth path, which means one with a high trend rate of growth and with limited fluctuations.
Figs 8a (top left) and 8b (bottom right)

Fig 8c.
Fig 8d. Linearized employment trends for different inter-sector delays.

Figs. 8. Effect of inter-sector coordination on the aggregate employment growth path.

Fig 8a and 8b show two different scenarios, a semi-fast (8a) and a semi-slow (8b) slow one, corresponding to two different inter-sector delays, or equivalently to two different rates of entry of new sectors into the economic system. Fig 8d shows the linearized slopes of the employment growth trend corresponding to five different scenarios in which rate of entry of new sectors into the economy is varied. The slopes are obtained by linearizing the portion of the aggregate employment curves foiling the emergence of the first sector. Fig 8d shows that the rate of growth of employment rises systematically as the rate of entry of new sectors into the economy increases. Furthermore, in addition to affecting the slope of the employment growth path, inter-sector coordination affects also the fluctuations in employment arising from the patterns of growth and decay of different sectors. Fig. 9 shows the combined effects of inter-sector coordination on the slope and on the fluctuations of the employment growth path. As we can see from Fig 9, the rate of the employment growth rises with a growing rate of entry of new sectors but the fluctuations behave in a more complex way, increasing first, the falling and subsequently increasing again. Considering that a sustainable economic development is likely to require a high rate of employment growth but low employment fluctuations, we are tempted to say that the most sustainable economic development paths are likely to be found at the centre of Fig 9.
Fig 9. Influence of the rate of entry of new sectors on the rate of growth and on the fluctuations of employment.

In summary, these experiments, although still limited, prove that inter-sector coordination can exert an important influence on the rate of growth and on the fluctuations of employment, and therefore on the sustainability of economic development. More precisely, a growing rate of entry of new sectors into the economy raises the rate of employment growth but has a more complex effect on the fluctuations of employment. To explore the conditions required to give rise to the most sustainable economic development paths requires further work.

2.4) The co-evolution of technologies and institutions.

Another factor which is likely to affect the dynamics of emergence of new sectors and their subsequent acquisition of economic ‘weight’ is the co-evolution of technologies and institutions. In our model, for the time being, we have only financial institutions. However, the model exemplifies the nature of the problem. In the model firm entry into a sector is determined by the product of adjustment gap (market size) and of financial availability. In the model financial availability represents the fraction of financial resources that the economic system is prepared to allocate to the emerging sector by appropriate institutions. As the nature of emerging sectors changes, for example as they become more science based, new financial institutions adapted to the situation are likely to be required. Venture capital firms and the role they played in the emergence of start-ups are but one example of this type of
institutional innovation. In the simulations we carried out so far we kept the term $FA_i^t$, representing financial availability, constant, thereby effectively eliminating co-evolution. Co-evolution can be introduced by having $FA_i^t$ at a given time dependent on the previous evolution of the system. For example, this can be done by having $FA_i^t$ dependent on the number of firms, on the output or on the demand in sector $i$ at a previous time. The use of these representations of $FA_i^t$ corresponds intuitively to a pattern of development in which the observation of previous development and of development potential in an emerging sector $i$ induces innovation in financial institutions. This increases the supply of financial resources to sector $i$, thereby raising the output of sector $i$ and the inducement to supply further financial resources. It is also clear how in absence of perfect foresight by economic agents co-evolution can lead to bubbles when potential developments are overestimated. Here we report the results of a series of experiments in which the strength of the feedback process from the development of the market to that of financial availability and back is varied. This is obtained by using for $FA_i^t$ the following expression:

$$FA_i^t = k_5 \cdot \left[ 1 + k_x (dN_i^t - dN_{tot}^t) \right]$$

Fig. 10. Influence of the strength of the feedback process from market size to financial availability and back. The strength of feedback is measured by the constant $k_x$ in Eq 6.
The presence of co-evolution of technologies and institutions can also be interpreted as an example of autocatalysis. Autocatalysis occurs when a process using given inputs produces some of the same inputs amongst its outputs. In this case the process will be speeded up and the emerging sector will achieve more rapidly its economic weight. Autocatalysis is likely to play an important role in structural change and it is a distinctly non linear feature of economic development which theories of complexity (Nicolis, Prigogine, 1989) describe as a necessary condition for the emergence of structure in homogeneous systems. In our case co-evolution will interact with the shape of the ILC and with inter-sector delays in determining macroeconomic development paths.

2.5) Variety

Going back to our hypotheses about variety and efficiency, we find in the results of this model a partial confirmation of the first hypothesis. For example, we find that faster entry of new sectors leads to a higher rate of growth of variety and to a higher rate of growth of employment. However, growth in variety is a necessary but not a sufficient condition for the sustainability of the economic development process. Given that now we measure variety as the number of sectors in the economic system, variety grows when the number of sectors grows. However, if the new sectors created are very small they may not compensate for the loss of employment entailed by the evolution of pre-existing and mature sectors. The measure of variety we use now is limited since it does not take into account the internal variety of each sector, arising for example from product differentiation. The use of a more accurate measure of variety could help us to improve our understanding of the role of variety in economic development. This will be the object of future work on this model.

3) SUMMARY AND CONCLUSIONS.

In summary, in this paper we use a modified version of a model of economic development by the creation of new sectors that we previously developed to investigate the impact of the shape of the ILC, of inter-sector delays and of the co-evolution of technologies and financial institutions on macroeconomic development paths. We find that while suitable combinations of these microeconomic phenomena can lead to balanced growth paths, other combinations can lead to unbalanced (i.e. either with low growth or with excessive fluctuations) paths. In this paper we find both a confirmation of the role of output variety in economic development and a refinement of the hypotheses considering variety growth as a necessary requirement.
Not only variety needs to grow, but the individual microeconomic instances of variety growth must be well coordinated to provide a balanced macroeconomic growth path.

REFERENCES


