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An evolutionary model of industrial growth and structural change

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Abstract

This paper analyses the determinants of structural change and aggregate productivity growth on the basis of the aggregation of the behaviours of heterogeneous firms in different economic sectors. At the same time this model accounts for the evolution of market structures by providing a consistent generalisation of standard replicator dynamic models, which focus only on a single industry. This paper shows that understanding structural change has to be grounded on a macroeconomic consistent aggregation mechanism reflecting the underlying theory of sorting and selection. It also shows that the combined effect on sectoral output growth of selection on firms' unit costs and sorting by income elasticities of sectoral demand depends upon the specific institutional characteristics of the market, upon the specific position that a sector occupies in the whole economy, in terms of product characteristics and substitutability and, finally, upon the output growth and average unit costs of substitute sectors. Moreover, the selection process and the institutional settings in which it unfolds, combined with sectoral income elasticities, guide aggregate productivity growth, which can display positive values even without technological change at firm level.

JEL classification: L1; O30; O41

Keywords: Structural change; Selection and sorting; Evolution of industries; Heterogeneity

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"The combination of diversity and seperateness was a permissive condition of modern economic growth." (Kuznets, 1989; p. 21)

1. Introduction

This paper contributes to the field of evolutionary economics and moves it in the direction of a more general approach to evolutionary thinking in economics. It explores the properties which connect the distribution of heterogeneous firms to the growth of industries, and the mechanisms that account for changes in the relative weight of different sectors (i.e. structural change) within an economy. Aggregate productivity growth is analysed as the result of the aggregation and interdependence of heterogeneous firms and sectors and is guided by the selection mechanisms within and between industries. Moreover, the impact of sector-specific income elasticities of demand is analysed.

A great amount of literature has recently deepened the analysis of the nature and properties of industry evolution (Dosi et al., 1995; Metcalfe, 1998; Malerba et al., 1999; Winter et al., 2000). Rather than analysing patterns of evolution and market share dynamics within a single industry, this paper provides an attempt to generalise some basic evolutionary properties in a multi-sectoral economy in order to understand the determinants of structural change and to look at the relationship between heterogeneity at the micro and sectoral level and aggregate productivity growth.

Accordingly, this model, which builds on Metcalfe (1994, 1998, 1999) provides a bridge between two levels of analysis. The first level addresses firms' behaviour and industrial dynamics and the second addresses the forces that drive different patterns of development of different sectors and their impact on the aggregate labour productivity growth rate. The aim of the paper is not to provide a general evolutionary model of growth, but rather to focus on the channels through which diversity is related to non-uniform growth.

In the evolutionary tradition, microfoundations rest upon bounded rational agents, which are characterised by regular patterns of behaviour embedded in production and accumulation routines. Accordingly, firms differ and generate a population distribution over unit costs. The properties of the relation between the structure of the population, the variety of behaviours and the dynamics of the population moments has been shown at the sectoral level with Fisher's Principle (Metcalfe, 1998) method. This paper moves on and explores whether similar properties hold in a multisectoral world with a continuous variation in the relative importance of different economic sectors. In addition, it shows that structural change and non-uniform growth depend upon a combination of demand-side (in the Pasinetti traditon) and supply-side factors, based on selection processes. The interplay of these two forces and a consistent aggregation mechanism of microeconomic behaviours account for patterns of productivity growth at macroeconomic level.

2. Structural shifts

One of the most striking stylised facts of long-term and medium-term economic development is the continuous process of transformation in the sectoral composition of economic activity. This is evident at different levels of aggregation. The economic literature has focused mainly on the major shift in terms of relative employment from agriculture, to manufacture and then to services. At the same time there is an equally evident and important degree of turbulence also within manufacture and service activities[1]. The question is then why industries grow at different rates and which are the mechanisms through which industries come to have an increasing weight in the total output while others decline and eventually wane.

Even if this phenomenon stands out as a fundamental characteristic of the development processes and a key component in accounting for the rate and direction of aggregate productivity growth, the traditional economist's tool box has been more often conducive to the analysis of the growth processes in terms of uniform expansion rather than of change. Undoubtedly the expansion of a homogeneous aggregate is analytically more tractable. Nevertheless it seems, by definition, difficult to investigate structural change without dropping some standard assumptions of many new growth models, e.g. homothetic preferences and absence of Engel effects on the demand side and total factor productivity growth without systematic sectoral effects on the supply side. Also reliance upon rational expectations[2], perfect factor substitutability and instantaneously clearing markets seem particularly problematic to this purpose (Syrquin, 1994). Recent endogenous growth models have abandoned the hypothesis of a single industry economy and have assessed the determinants of aggregate growth in a multi-sectoral economy (Romer, 1990; Aghion and Howitt, 1992, 1998). These models despite being insightful on the conditions required for a steady-state growth path, still incur difficulties in explaining major processes of structural changes, sector interdependence and transfer of resources across different industries. Aghion and Howitt (1998) recognise that these models "... miss the stages of development in which resources are gradually reallocated from agriculture to manufacturing and then to services, all with different factor requirements and different technological dynamics. The economy is always a scaled up version of what it was years ago, and no matter how far it has developed already prospects for future development are always a scaled up version of what they were years ago".

[1] Schumpeter (1928), Young (1928), Kuznets (1971, 1989) provided seminal insights on the importance of the processes of structural change. Among the rich literature on this topic, evidence of structural shifts is provided and discussed in Fisher (1939), Clark (1940), Kravis et al. (1983), Baumol et al. (1985), Momigliano and Siniscalco (1986), Syrquin (1994), Metcalfe (1998, 1999). For a discussion, see also Prosperetti (1986), Ercolani (1994).

[2] Aghion and Howitt (1994) stress that the assumption of rational expectations is one of the limitations of endogenous growth theory. This is particularly true "...in a theory where the centre of attention is the costly and slow acquisition of knowledge about how to master technology." (Aghion and Howitt, 1994)

Other authors have emphasised that patterns of sales growth within industries follow a cycle of growth, maturity and decline (Vernon, 1966; Audretsch, 1987). In this conceptual framework, industries develop around a radical innovation. In a first phase, low barriers to entry and a not well defined market allow a large number of new firms in the sector and high diversity in the design activity. Subsequently there is a second phase of high growth characterised by the emergence of a dominant design, economies of scale and, if network externalities emerge, also increasing returns to adoption. The final phase is characterised by selection mechanisms based on prices and costs, an 'industry shake-out' is likely to occur and is originated by a decreasing rate of entry and by the exit of the less efficient firms which are not able to supply a competitive dominant design (Utterback, 1994; Klepper, 1996; Miozzo and Montobbio, 2000).

As a result, at a given point in time, industry growth rates are different because of their position in the life cycle. Of course this is a highly stylised picture which tells just a part of a story. Klepper (1997) signals that "it seems clear that the product life cycle has limited relevance for a sizeable number of products". The industry life cycle literature helps in raising some important questions about structural change. First the role played by patterns of demand in both the emergence of a dominant design and the length of the stages of the product cycle. Second it remains to be explained which are the mechanisms which link the growth and the decline of different sectors and regulate sectoral interdependence.

At a aggregate level there is a wide literature which analyses the impact of both supply and demand side factors to explain processes of structural change and in particular the structural shift between primary, secondary and tertiary sectors. Firstly Schumpeter (1928) and Kuznets (1971) not only pointed at the relevance of structural change as a major fact in modern economies but emphasised sectoral interdependence in order to understand aggregate patterns of growth. In particular Kuznets (1989) has pointed to three major driving forces for these structural transformations, different impact of technological innovations, different income elasticities of domestic demand and, finally, a selection mechanism based on the "shifts in comparative advantage in international trade in tradable goods" (p. 15).

The recent economic literature leaves open the issue about the relative weight to be assigned to demand and supply forces in generating sectoral shifts. Fisher (1939), Clark (1940) have stressed, firstly, the role of demand factors. Conversely, Baumol (1967), Baumol et al. (1985) address the problem of uneven employment growth between service and manufacture activities in terms of supply side productivity differentials. Notarangelo (1999) encompasses in a unified framework Baumol and Pasinetti's model (1981, 1993), showing that the former can be interpreted as a special case of the latter. Pasinetti's result that sectoral shifts in the employment structure are a necessary condition for macroeconomic stability are confirmed and the sign of sectoral growth rates depends upon both productivity rates and trends in demand.

Two points are noteworthy. Firstly, Baumol (1967), Baumol et al. (1985) have emphasised that stagnant sectors in terms of productivity tend to absorb a relatively higher share of employment in the economy. Correspondingly, they underline the labour saving effects of sectoral productivity growth in the declining sector (in employment terms) in order to explain the employment shift from agriculture to manufacturing and from manufacture to services. In particular, Baumol shows that if output shares are driven by exogenous forces (e.g. high income elasticity and low price elasticity) less progressive sectors (e.g. retailing and higher education) tend to absorb a growing proportion of labour inputs relatively to other sectors. Within a different theoretical framework Metcalfe (1999) takes into account the mutual determination of sectoral productivity growth rates and ends up with similar implications. Differential output growth rates are influenced by income elasticities, sectoral productivity growth rates are mutually determined and consequently so are the relative industrial shares in terms of employment[3].

Secondly, as emphasised by Pasinetti (1981), the sectoral differentiation of income elasticities of demand affects importantly structural changes and patterns of aggregate growth. Moreover, he stresses that these elasticities are not constant over time because they are the result of the aggregation of individual Engel's curves and that, in turn, they depend on the income, sex and age distributions of consumers within the economy.

This work moves on and sheds new light on the determinants of sectoral shifts and non uniform growth using an evolutionary approach. Uniform growth occurs when all sectors grow at the same rate and do not change their weight in the economy, accordingly there is no structural change. The main purpose of this paper is to show that productivity growth, at sectoral and aggregate levels, is the result of a general evolutionary process. Selection mechanisms act at industrial and economy levels and diversity is micro founded at a firm level. Uniform growth turns out to be a very special and implausible case.

Secondly, the properties of this system are singled out in terms of dynamics of market structures within industries, determinants of the different rates of sectoral output growth and of aggregate productivity growth. This model is able to account for the possibility that high productivity sectors increase their output *and* employment shares. This phenomenon which characterises structural change within macro sectors like manufacture and services is not grasped by Baumol's model and is based on the idea that sectoral productivity levels drive sectoral selection via decreases in sectoral unit cost levels.

Finally, we emphasise that understanding structural change is grounded in the aggregation mechanism which is used and, therefore, on the weighting scheme adopted. This paper, in this respect, emphasises the importance of elasticity of substitution and sectoral 'proximity' in terms of market arrangements, which allow

[3] The empirical evidence, while not inconsistent with these predictions, is not unequivocal in this respect. Structural shift towards service activities is more discernible in terms of employment rather than in output shares (Baumol et al., 1985; Ercolani, 1994). Moreover, it has been shown that TFP levels in manufacturing tend to be higher than in agriculture and services for extended period. At the same time, the structural shift to manufacture has always been accompanied or preceded by a significant rise in productivity in agriculture (Syrquin, 1994). It is also true that within services there are high productivity activities which expand also in terms of employment shares.

consumers to change product (knowledge dispersion about rival offers, visibility and channels of distribution and customer loyalty).

The basic assumptions of the model and its properties at the industrial level are addressed in Section 3. Sections 4 and 5 investigate the mechanisms through which diversity, in terms of firm and sectoral characteristics (accounted for by the appropriate aggregation scheme), and sectoral interdependence drive and constrain the aggregate paths of productivity growth. In particular, Section 4 analyses the selection and sorting processes across sectors (Sections 4.1 and 4.2) and the way they affect industrial growth and decline (Section 4.3) and market share dynamics within industries (Section 4.4). Section 5 shows the relation between the different levels of heterogeneity and the aggregate patterns of productivity growth.

3. The evolutionary dynamics in one sector

In this section, we outline a simple baseline model of industry evolution characterised by firms heterogeneity in terms of unit costs, mark up pricing and selection. The dynamics of firms market shares depends upon the characteristics of the population and the type of selective process. In what follows we illustrate the basic hypothesis of the model and its main properties, which are also used in its generalisation in Sections 4 and 5. A microfoundation is provided in terms of firm behaviour and demand (Section 3.1) and the sectoral dynamics is analysed building on the basic principles of variety and selection (Section 3.2).

3.1. The hypothesis of the model

Assume there is a population of heterogeneous firms which produce the same commodity with their own specific process of production[4]. Within evolutionary theories, micro-diversity at firm level is related to the idea that technology has to be kept distinct from the concept of *technique* based on factor proportions. Rather technology is composed by artefacts and heuristics, which are highly firm-specific. Heuristics are assumed to emerge on a knowledge base, which is partly tacit, cumulative and, consequently, highly idiosyncratic (Nelson and Winter, 1982; Dosi, 1988). Moreover agents have bounded rationality and they learn routines[5], in order to face selective pressures. We assume that routines do not change over time and that, ultimately, competitiveness of any firm in the population is determined by its costs per unit of output (h_i).

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[4] In this section the main assumptions of the basic Metcalfe's model (1998) are used. In Section 3.2 some results on the dynamic properties of the distribution of firm behaviours and selection mechanisms are singled out from Metcalfe (1998) and discussed as a basis for the generalisation provided in Section 4.

[5] Conlisk (1996) addresses the empirical and theoretical reasons for incorporating bounded rationality in economic models, Cohen et al. (1996) discuss the concept of routines and of other recurring action patterns of organisations.

In the industry there are n firms, which differ in the unit labour requirement and have the same unit capital requirement (Metcalfe, 1998):

$$h_i = a_i + bR \quad a_i = \frac{L_i}{Y_i}; \quad b = \frac{K_i}{Y_i} \tag{1}$$

R is the cost of capital relative to the cost of labour (which is 1). In what follows we assume also that since routines are permanent, firm's production does not deviate form the constant return to scale process a_i. Note that the possibility of inducement effects on technological choices is excluded *ab origine* simply because factor prices are assumed to be constant and factor coefficients are fixed.

Let us further assume that the rate of expansion of firm i's output depends on unit profit margin (m_i). Firms are assumed to invest a constant part f_i of $m_i = p_i - h_i$ where p_i is firm i's price. f_i embodies decision routines which can be firm specific and depend on the characteristics of specific financial markets. For sake of simplicity, we will assume that f is the same for all firms[6].

$$\frac{\dot{y}_i}{y_i} = f_i m_i = f_i(p_i - h_i); \quad \text{if} \quad (p_i \leq h_i) \quad \text{then} \quad \frac{\dot{y}_i}{y_i} = 0 \tag{2}$$

y_i is firm i's output; p_i is firm i's price; f_i is the propensity to accumulate. It is assumed that if output growth is zero firms stop producing and are out of the market.

Price setting and output decisions depend also on the average behaviour of the population of the n firms in the market and on the selection mechanism. This is the second important building block of any evolutionary model, heterogeneous firms interact in a specific evolutionary environment (in this case the product market) and their different abilities are reflected in a variety of firm-specific price levels. This affects the evolution of their customer base and, in turn, their market shares.

$$\frac{\dot{y}_{\mathrm{D}i}}{y_{\mathrm{D}i}} = \frac{\dot{y}_{\mathrm{D}}}{y_{\mathrm{D}}} + \delta(\bar{p}_s - p_i) \quad \bar{p}_s = \sum_{i=1}^{n} s_i p_i \tag{3}$$

$\dot{y}_{\mathrm{D}i}/y_{\mathrm{D}i}$ is the firm-specific rate of demand growth; δ is the coefficient which measures the impact on demand growth of a change in the firm i price deviation from the average price (Phelps and Winter, 1970). In particular δ grades the extent to which consumers are able to switch to another brand and, ultimately, the speed of the selection process and the intensity of competition. If $\delta = 0$ the market is fully segmented and each firm acts as a monopoly within each market segment (the customer base is fixed and independent from the position of the firm in the price structure), if $\delta = \infty$ markets are competitive and firms are price takers. Here it is assumed that the value of δ is between these two extremes because of the existence of a number of 'barriers to switching' such as consumers' imperfect knowledge about marketed products, consumers' brand loyalty and institutional imperfections of market mechanisms.

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[6] A microfoundation of Eqs. (2) and (3) is provided in the Appendix A.

3.2. The diversity destruction process

The properties of this evolutionary model are discussed at length in Metcalfe (1998). We recall here the basic principles of this evolutionary dynamics in terms of firms' market share and population properties as a groundwork for the analysis of market share dynamics and population properties in a multisectoral economy.

Proposition 1. *Price, unit profit margin, and output growth rate deviations from the weighted population mean are proportional to unit cost deviations from the weighted population mean. Institutional changes, interpreted as increased competition in terms of product substitutability and easier access to financial resources, speed up the selection process.*

The system of Eqs. (1)–(3) can be solved for the single firm. Firms with a positive unit profit margin set jointly prices and output in order to match capacity and demand growth, given their unit cost structure. From (Eqs. (2) and (3)) it can be shown that in each instant of time there is just one price level such that this condition is met (*normal price*). Firms, then, set normal prices because they try to have a balanced growth avoiding on one side a growing stock of unsold commodities and, on the other side, capacity shortage.

It is possible to show that the dynamics of the model is driven by the unit cost deviations from the population mean which affect price, profit margin and, in particular, growth rate differences across firms.

$$\frac{\dot{y}_i}{y_i}-\frac{\dot{y}_{\mathrm{D}}}{y_{\mathrm{D}}}=-\Delta(h_i-\bar{h}_s) \quad \Delta=\frac{f\delta}{f+\delta} \tag{4}$$

Firm performance in term of market share growth depends on the relative position in term of unit costs in the population of firms. The competition process determined by firms' price behaviour unfolds subject to given unit costs, to the exogenous demand growth rate and to the institutional set up.

Changes in the values of δ and f capture the institutional modification of the intensity of competition and access to financial resources. The coefficient Δ is called 'market selection coefficient' (Metcalfe, 1998), is an increasing function of δ and f and measures the selective pressure on firms. A higher market selection coefficient accelerates the rate of change of firms market share and, therefore, selection.

In particular, if $\delta=0$, firms act as monopolies in their own market niche and grow at demand growth rate. Accordingly price variance equals to unit cost variance and unit profit margin is the same for all firms. A higher δ, due for example to an improved consumers' ability to switch to a cheaper product, constrains firms price behaviour and reduces market imperfections because prices are kept relatively more concentrated than unit costs, around the weighted population average.

A higher value of f is an easier access to financial markets for all firms in the sector. It reflects either a higher propensity to accumulate by firms, or a higher portion of external financing expressed in terms of internal profit. In this circumstance, firms are able to balance capacity growth and firm-specific demand growth with a lower normal price.

Proposition 2. *Firms are driven out of the market in two circumstances, when firms' unit profit margin becomes zero or when their market share becomes zero. The likelihood that firms' unit profit margin is driven to zero and, as a result, that firms exit with a positive market share, depend negatively on demand growth and on cross-firm weighted unit cost average.*

Solving equations Eqs. (1)–(3) it can be obtained that $m_i > 0$ if:

$$h_i < \Psi(\bar{h}_s) = \left[\frac{1}{\Delta}\right]\frac{\dot{y}_{\mathrm{D}}}{y_{\mathrm{D}}} + \bar{h}_s \quad (5)$$

Again the evolutionary result that firms' behaviour is affected by the structure of the population of firms is evident. Unit cost weighted average is decreasing along industry evolution because of the market share shift in favour of the more efficient firms. As a result Eq. (5) expresses a ceiling which becomes more and more binding as industry evolves.

Moreover, it is interesting to stress that the ceiling Ψ is a negative function of the market selection coefficient and, therefore, is lower the higher is δ and the higher is f. Finally it is worthwhile noting that Ψ is a positive function of the sectoral output growth. This might confirm the intuition of product life cycle theories claiming that at a later stage of the cycle, when industry growth rate slows down, industries observe an increase in the rate of exit.

Proposition 3. *The rate of reduction of the population average unit cost depends on the variance of the population unit costs and it is positively related to the market selection coefficient.*

In this model the engine of evolution is market share (s_i) dynamics determined by the firm's unit cost distance from the weighted population mean. Of course since s_i changes over time $\bar{h}_S$varies as well, in particular:

$$\frac{\partial \bar{h}_s}{\partial t} = \sum \dot{s}_i h_i = -\Delta \sum s_i (h_i - \bar{h}_s) h_i = -\Delta V_s(h) \quad (6)$$

This result shows that the rate of reduction of the population average unit cost depends positively on the variance of the population unit costs and on the market selection coefficient Eq. (6) is called The Fundamental Theorem of selection or Fisher's Principle by Metcalfe, 1998. The structure of the industry unit costs determines not just market shares but also their dynamics and the pace of industrial evolution. This pace is not constant because as market shares shift, unit cost population average and variance change. As firms with below average unit costs increase their market share, $\bar{h}_S$ decreases[7]. As a result as industry evolves over time

[7] Market share shifts imply also that the average price is decreasing over time. Accordingly firms' normal prices and, consequently, output growth rates are falling.

all firms, with the exception of the best practice one, will find themselves sooner or later with an above average h_i and a declining market share.

Note that the speed of concentration in the market depends on the degree of selective pressure (Δ). If, in particular, consumers' ability to recognise more quickly the product brand with a lower price improves, the rate of change of market shares is increased. This result is interesting because it shows that a more efficient market arrangement, in terms of knowledge diffusion, accelerates the concentration process within an industry. At the same time the attenuated degree of market imperfection, while concentrating price making around the population average, does not imply a reduction in the market power of the best firms.

This framework, used here to assess the basic principles of evolutionary dynamics can be extended and generalised along many different lines of enquiry to account for the observed properties of industrial evolution and market share dynamics. Firstly the important assumption on a 'de-strategised' firm behaviour, based on the idea that firms persistently differ in their organisational routines, can be articulated assuming the existence of different technological regimes which affect learning processes within industries and consequently the evolution of industrial structures (Winter, 1984; Dosi et al., 1995).

Secondly unit costs are not the only important source of heterogeneity across agents. In this model firms remain locked in sub-optimal production routines and gradually exit the market. Efficient markets sweep off firms with normal unit costs below the average. At the same time process and product innovation is the force, which recreates variety and counterbalances the tendency in the direction of market concentration (Dosi et al., 1995; Saviotti and Mani, 1995; Malerba et al. 1999). Third, and consequently, the characteristics of industrial dynamics can be determined by stochastic processes which continuously recreate variety in terms of firms' technological features or product characteristics (Winter et al., 2000; Malerba et al. 1999; Saviotti and Mani, 1995).

This paper follows a different line of enquiry and, rather than analysing patterns of industrial and market share dynamics, generalises these basic evolutionary properties in a multi-sectoral economy to understand the determinants of the differential rates of growth of sectors and to look at the properties of a general evolutionary dynamics.

4. Patterns of structural change: sorting and selection

The challenge is, in this section, to extend the model at a multi-sectoral level in order to enquire which are the determinants of structural change and which restrictions have to be introduced in order to have uniform growth. However, since we show that in general with heterogeneous agents growth is non uniform, specific institutional characteristics of countries and the typology of specialisation is expected to affect importantly aggregate patterns of productivity growth. This is the topic of Section 5 where we show that, when sorting and selection take place, diversity (in terms of firms' and sectoral average unit costs and income elasticity of sectoral demand) guides the aggregate patterns of productivity growth.

Assume then that the evolutionary dynamics in a multi-sectoral economy depends upon two mechanisms: sorting and selection. Sorting is a process in which sectors experience differential growth driven by exogenous forces within an economy that grows at a constant exogenous rate. The sorting mechanism is based on the idea of a variation in the industrial composition of demand, as income grows. In particular it is assumed that this variation is brought about by sectoral differences in income elasticity of demand (Pasinetti 1981, 1993; Metcalfe, 1998)[8].

Moreover assume that sectors are interdependent because firms compete not just within their population but also with firms that belong to other populations producing substitute goods with a different set of routines and technologies. This implies a modification of the selection equation (Eq. (3)) to account for substitutability across sectors. Sorting and selection processes differ because sorting takes place, as it will be shown, also when sectors are completely independent while selection requires interdependency across sectors and substitutability among products.

4.1. The selection mechanism

Let us assume, as in Section 3.1, that firms invest a constant part of their unit profit and that f is the same for all firms in sector j. This reflects the idea that access to financial markets and the properties of the accumulation process are affected by sector specific conditions. At the same time the selection equation has to be modified in order to account for various degrees of product substitutability across sectors. In particular firms compete not just with other firms within the same industry but their market shares are also the result of price differentials with substitute products in related sectors [9]:

$$\dot{s}_i^j = \sum_{k=1}^{n^1} d^{j1} s_i^j s_k^1 z^1 (p_k^1 - p_i^j) + \ldots + \sum_{k=1}^{n^m} d^{jm} s_i^j s_k^m z^m (p_k^m - p_i^j) \tag{7}$$

for $j = 1, \ldots, m$ sectors and $i = 1, \ldots, n^j$ firms.

Eq. (7) describes the demand share change of firms i in sector j. Note that subscript indexes refer to firms and superscript indexes refer to sectors. Firm i, in principle, competes with all firms in m sectors. $n^1, n^2, \ldots, n^m$ are the number of firms in each sector. Consumers compare p_i^j (the price of firm i in sector j) with p_k^l (the price of firm k in sector l; the letter l indicates a generic sector with $l = 1, \ldots,$ m).

[8] As emphasised by Pasinetti (1981), this is a strong simplification because income elasticity of demand are considered exogenous and independent from the level of income and its distribution. Nevertheless, this simple sectoral differentiation, while keeping the model tractable, allows to develop the argument of the interplay between sorting and selection in the process of structural change which is the main point of the paper.

[9] The meso and macro economic consistency of Eq. (7) is thoroughly shown below.

d^{jl} coefficients are industry level measures of the rate to which buyers switch from sector j to sector l. They can be considered a measure of sectoral 'proximity' on the demand side. The value of d^{jl} depends on the degree of substitutability among products, on the market arrangements, which allow consumers to change product (knowledge dispersion about rival offers, visibility and channels of distribution), on customer loyalty to a specific product and, finally, on product quality (user-friendliness, reliability). Moreover this sectoral proximity index is related with the degree of selection pressure exerted by firms in sector l on firms in sector j. It is worthwhile noting that as long as d^{jl} is different from (and greater than) zero, there is some degree of substitutability between sectors j and l.

The overall result on demand share dynamics of firm i in sector j is subject to two weighting schemes. Firstly (as in Eq. (A.3)) in the Appendix A it is assumed that the probability for a firm product to be compared with other products is proportional to its market share in its sector. Secondly the probability that firms in sector l are compared with firm i in sector j is proportional to z^l, which is the market share of sector l on the entire economy. Accordingly the probability of a demand switch upon 'contacts' between firm i in sector j and firms in sector l, depends also on the size of sector l. Each sectoral output is expressed in terms of the same commodity unit whose relative prices are constant.

This composed weighting scheme brings about the following consequences, the scalar $v_k = s_k^l z^l$ is equivalent to the market share of firm k in the entire economy. It follows that, according to Eq. (7), the rate to which consumer choices switch from firm i in sector j to firm k in sector l is influenced by the market share of firm k in all the economy. Finally, if there is just one sector in the economy, Eq. (7) is equivalent to Eq. (3) and d^{ij} is equal to δ.

4.2. The sorting mechanism

Assume, as in Section 3.1, that there is an exogenous rate of growth of sectoral demand and that it depends on aggregate output growth through the value of the elasticity φ^j:

$$\frac{\dot{y}_D^j}{y_D^j} = \varphi^j \frac{\dot{y}}{y} \tag{8}$$

φ^j is the economic growth elasticity of sectoral demand; $\dot{y}/y$ is the rate of growth of the whole economy and is taken as exogenous. Eq. (8) defines the basic mechanism that underpins the sectoral sorting process. Eqs. (1), (2), (7) and (8) provide jointly the basic equations of the model and are the assumptions that drive the general evolutionary dynamics that this paper is aimed at studying.

4.3. Sorting, selection and industrial growth

It can consistently be assumed that coefficients d^{jl} represent symmetric relations of substitution among sectors and, as a result, that the matrix $\mathbf{D}_{\mathrm{SECT}} = [d^{jl}]$ is symmetric as well. Solving the m sum elements and knowing that $\dot{s}_i^j = s_i^j(\dot{y}_i^j/y_i^j - \dot{y}^j/y^j)$, the selection Eq. (7) for firm i in sector j becomes:

$$\frac{\dot{y}_i^j}{y_i^j}=\frac{\dot{y}^j}{y^j}+\sum_{l=1}^{m} z^l d^{jl}(\bar{p}_s^l-p_i^j) \tag{9}$$

$\bar{p}_S^l=\Sigma_{k=1}^{n^l} s_{i}^l p_i^l$ is the weighted price average for sector l where weights refer to firms' market shares within sector l.

Output decisions of firms i in sector j depend not only on the weighted average price in sector j but also on the weighted average price in the other $(m-1)$ sectors. All firms in all sectors set jointly normal prices and output growth rates (according to Eqs. (2) and (7)) in order to have balanced growth, that is avoiding insufficient capacity growth or, rather, capacity shortage.

The rate of output growth of sector j is obtained summing up Eq. (9) for all firms i in sector j and using firms' market share in sector j as weights. The result is that:

$$\frac{\dot{y}^j}{y^j}=\frac{\dot{y}_{\mathrm{D}}^j}{y_{\mathrm{D}}^j}+\sum_{l=1}^{m} z^l d^{jl}(\bar{p}_s^l-\bar{p}_s^j) \tag{10}$$

This is the selection equation at sectoral level and shows that sectoral output growth depends upon the exogenous rate of demand growth and upon the relative industrial average price of industries.

The evolutionary mechanism outlined in Eq. (10) is consistent and appropriate to express the relative growth of sectors. This can be shown through the aggregation of Eq. (10), a process that recovers the exogenous aggregate rate of growth.

$$\sum_{j=1}^{m} z^j\frac{\dot{y}^j}{y^j}=\frac{\dot{y}}{y}+S$$

$$S=\sum_{j=1}^{m} z^j\sum_{l=1}^{m} z^l d^{jl}(\bar{p}_s^l-\bar{p}_s^j)=\mathbf{z}'\{\bar{\mathbf{P}}\mathbf{D}\text{SECT}-\mathbf{D}\text{SECT}\bar{\mathbf{P}}\}\mathbf{z}=0$$

$$\mathbf{z}'=[z^1,\ldots,z^m]$$

$$\bar{\mathbf{P}}=\begin{bmatrix}\bar{p}_S^1 & 0 & \ldots & 0\\ 0 & \bar{p}_S^2 & \ldots & 0\\ \ldots & \ldots & \ldots & \ldots\\ 0 & 0 & \ldots & \bar{p}_S^m\end{bmatrix} \tag{11}$$

Eq. (11) shows that all micro interactions, implied by Eq. (7), are consistent at a macroeconomic level (The proof follows the lines indicated in the Appendix A). Firm-level rates of output growth, when summed with appropriate weights across firms and across sectors cannot give a result that is different from the rate of growth of aggregate output.

In order to investigate the determinants of sectoral output growth, we can solve for sectoral average prices and substitute them in Eq. (10)[10]. Accordingly the m average sectoral output growth equations can also be expressed in terms of a separate system of m equations:

[10] At a sectoral level, average price is: $\bar{p}_s^j=((\dot{y}^j/y^j)/(1/f^j)+\bar{h}_s^j$.

$$\frac{\dot{y}^j}{y^j} = \Delta^j\left[\frac{1}{\bar{d}_z^j}\varphi^j\frac{\dot{y}}{y} + \frac{1}{f^j}\sum_{l=1}^{m} w^{jl}\frac{\dot{y}^l}{y^l} + \left(\sum_{l=1}^{m} w^{jl}\bar{h}_S^l - \bar{h}_S^j\right)\right] \tag{12}$$

$$\bar{d}_z^l = \sum_{l=1}^{m} z^l d^{jl}$$

$$w^{jl} = \frac{z^l d^{jl}}{\bar{d}_z^j}$$

$$\Delta^j = \frac{f^j \bar{d}_z^j}{f^j + \bar{d}_z^j}$$

Sector j output growth is composed of three elements. Firstly φ^j describes the sorting mechanism: the higher is the value of elasticity of demand, the higher is the output rate of growth. If all sectoral 'proximity' coefficients (d^{jl}) are zero, just the sorting process drives the path of growth. The second element embodies the relevance of the sectoral connections among average output rates of growth. Note that, *coeteris paribus*, a higher rate of growth in sector l, affects positively the rates of growth in all the other sectors. The size of this effect depends, according to our weighting scheme, on the demand proximity of sectors and on their share in the total economy.

Finally there is a direct sectoral selection process based on differential average unit costs, the distance between sector j average unit costs and the weighted average for all sectors affects industrial output growth. Those sectors, which on average are able to produce at a lower cost, will gain consumers and grow faster.

It is worthwhile emphasising that the appropriate evaluation of the selection environment and with it the understanding of sectoral differential growth, should consider average unit costs of sectors weighted with special indexes (w^{jl}) which should include not only the relative size but also the proximity in terms of product substitutability. This suggests that economic and institutional elements have to be taken into account in the process of aggregating the relevant variables and that the aggregation scheme and the relative weights are a crucial issue for understanding the evolutionary dynamics.

The important point here is that sectoral output growth depends upon a specific combination of sectoral characteristics (in part the result of competition and selection within the sectors) relatively to the (appropriately weighted) average of the relevant variables of the entire populations of firms and sectors. Heterogeneity guides fundamentally the dynamic of the system and the solution of the model and, therefore, the rate of growth of sectoral output, depends upon the degree and type of diversity in the economic system.

In order to understand how heterogeneity—in terms of firms unit labour requirement and unit costs, growth elasticity of sectoral demand and degree of substitutability (proximity) between sectors—affects sectoral growth, we solve the model in two steps according to different assumptions on the degree of variety that we allow in the system. In the first step we assume a constant rate of substitutability across sectors. In the second step we evaluate the impact of higher heterogeneity in terms of sectoral proximity. In both cases, we enquire into the properties of the evolutionary dynamics and the determinants of sectoral growth and we ask which conditions should apply for having uniform growth against structural change as widely assumed in the growth literature.

Consider then a benchmark situation in which variety is just in terms of firms characteristics (unit labour requirement) and sectoral income elasticity. This is an appealing and direct way to solve the model, considering a sub-group of sectors such that the matrix $\mathbf{D}_{\mathrm{SECT}}$ is composed of elements with the same value (call it d)[11] and to assume that f is the same for all sectors. This allows to greatly simplify the calculations, since Δ^j does not vary across sectors (then $\Delta^j = \Delta$, $\forall j$), and to figure out in a direct way the different roles of the sorting and selection mechanisms.

We can show the way sectoral output growth depends upon selection and sorting. The relative weight of these effects is determined by the institutional characteristics of the evolutionary environment (i.e. the value of income elasticity of demand, degree of product substitutability and propensity to accumulate). Moreover as higher product substitutability increases the selection pressure, sorting is less important as a determinant of structural change. Finally uniform growth turns out to be a very special case. In particular we put forward the following Proposition 4.

Proposition 4. *The sorting coefficient converges to one for all sectors as the degree of product substitutability goes to infinity. The impact of deviation from the population average unit cost (selection effect) depends positively on the value of market selection coefficient. Uniform growth occurs only if:*

– sectoral average unit costs ($\bar{h}_S^j$) do not change across sectors j and $\varphi^j = 1$ for all j or
– sectoral average unit costs ($\bar{h}_S^j$) do not change across sectors j and $d = \infty$.

Eq. (12), subject to the assumptions outlined above, becomes:

$$\frac{\dot{y}^j}{y^j} = \left(\frac{f\varphi^j + d}{f + d}\right)\frac{\dot{y}}{y} + \Delta(\bar{\bar{h}} - \bar{h}_s^j) \tag{13}$$

$$\bar{\bar{h}} = \sum_{l=1}^{m} z^l \bar{h}_s{}^l = \sum_{l=1}^{m} z^l \sum_{i=1}^{n^l} s_i^l h_i^l = \sum_{k=1}^{n} v_k h_k$$

$$n = \sum_{l=1}^{m} n^l \quad \text{is the total number of firms in the economy,}$$

$$v_k = s_k^l z^l = \frac{y_k^l}{y^l}\frac{y^l}{y} \quad \text{is the market share of firm } k \text{ in the entire economy,}$$

Sectoral output growth is then composed of two elements: sorting $((f\varphi^j + d)/(f + d)\dot{y}/y)$ and selection $(\Delta(\bar{\bar{h}} - \bar{h}_S^j))$, which reflect the distinctive features of the

[11] In principle for all the economy, there are no economic reasons to assume that $\bar{d}_z^j = \Sigma_{l=1}^m z^l d^{jl}$ (which is the z-weighted sum of the elements of row j in $\mathbf{D}_{\mathrm{SECT}}$) is the same for all sectors j (as it would be assuming that d is the same for all sectors in the economy).

sector: average unit cost and income elasticity. If d is zero, that is if sectors are completely independent, industries simply evolve exogenously driven by the sorting mechanism. If φ^j is one, the sectoral variance of the output rates of growth depends just upon sectoral selection.

The sorting coefficient is a monotonic positive function of φ^j and as expected is greater (lower) than 1 if growth elasticity of demand is greater (lower) than 1. Nevertheless the sorting coefficient converges to one as d goes to infinity. This means that as the environment becomes more selective because of a higher degree of substitutability among products, reduced knowledge dispersion about rival offers, or lower customer loyalty to a specific product, we have a reduced importance of the sorting mechanisms as a determinant of different rates of growth across sectors and structural change.

In order to have that all sectors grow at the same exogenous growth rate of the economy, the sorting and selection mechanisms should not work. Firstly, by definition, sorting is not effective if all income elasticities of sectoral demand are the same and if the rate of growth of the economy is zero. Secondly, as mentioned above, there is no sorting effect as d goes to infinity. This circumstance is close to perfect competition where products are perfectly substitutable and there are no reasons why the industrial composition of demand should vary across sectors, as income grows.

Selection is ineffective firstly if all sectors have the same average unit costs. This is highly implausible since we have seen in the previous section that within each sector, average unit cost decreases depending upon the unit cost variance across firms[12]. Secondly if Δ is zero. This is the case if there are no substitute products in the economy.

In general we have structural change and interdependence and the deviation of sectoral output growth from the rate of growth of the economy depends upon its relative position in terms of average unit costs and income elasticity of demand. The following proposition sets out more precisely the character of sectoral interdependency.

Proposition 5. *Given two substitute sectors k and l, sector l output growth is greater than sector k output growth if the difference between sectors k and l average unit costs is greater than a floor which depend negatively upon sectoral proximity, positively on the difference between sectors k and l growth elasticitiy of demand and, finally, positively upon the exogenous rate of output growth.*

The following applies[13] on the basis of Eq. (13):

[12] In Section 4.4 we show that this result holds also in this multisectoral economy.

[13] Note that this is not a *coeteris paribus* exercise. It is an *ex-post* comparison between the aggregate behaviour of two sectors. There is no direct causality between sector k and sector l variables. Fig. 1 is the outcome of the general evolutionary process.

$$\frac{\dot{y}^l}{y^l} > \frac{\dot{y}^k}{y^k} \quad \text{if} \quad (\bar{h}_S^k - \bar{h}_S^l) > E = \frac{1}{d}(\varphi^k - \varphi^l)\frac{\dot{y}}{y} \tag{14}$$

If $\varphi^k = \varphi^l = 1$ or $d = \infty$, E is zero, and average unit costs are the only force which drives differential sectoral growth. In Fig. 1, the process of structural change between two sectors is described assuming that the rate of growth of the economy is exogenous and that $\Delta\varphi = (\varphi^k - \varphi^l) > 0$. The sectoral rates of growth in relation to the values of $\Delta h_S = (\bar{h}_S^k - \bar{h}_S^l)$ are displayed. The first quadrant in Fig. 1 singles out the non-trivial situation where the sector k, with the higher elasticity, displays also the higher average unit cost[14]. Two different contingencies can emerge, if $(\varphi^k > \varphi^l)$, the rate of growth of sector l can still be greater, only if $(\bar{h}_s^k - \bar{h}_s^l) >$ E. In this case selection forces prevail. Conversely, if d is small enough, it is also plausible a situation where $E > (\bar{h}_s^k - \bar{h}_s^l) > 0$. In this case the more efficient sector is condemned to a lower growth because of a constraint on the demand side and because of a low level of the market coefficient.

Proposition 6. *If there is heterogeneity in terms of product substitutability between sectors the selection mechanism implies that sectoral growth depends upon the specific combination of the degree of substitutability across products and sectoral output growth and average unit costs. In particular, beyond the selection and sorting effects, a sector grows faster if it is 'closer' to sectors with relatively higher output growth and with relatively higher average unit costs.*

Adding a degree of heterogeneity, we show that sectoral growth is affected by the specific sectoral composition of the economy. It is particularly important the presence of substitute sectors, their growth rates and their level of unit costs. Considering from Eq. (12) that:

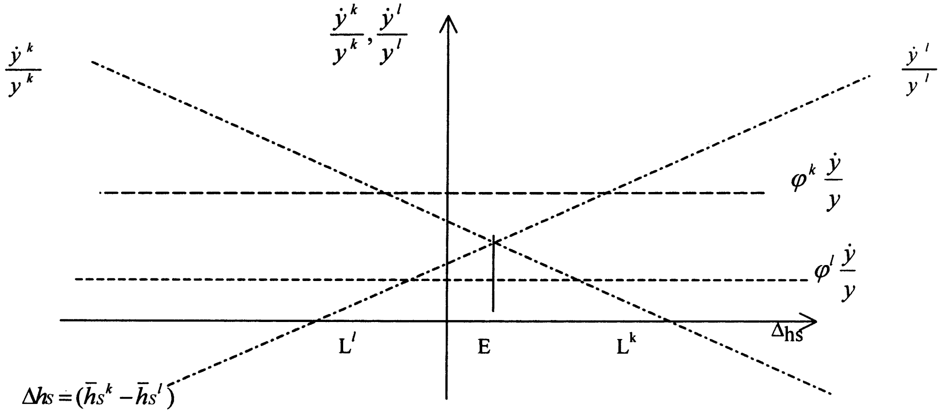

Fig. 1. Structural change and differential growth between two sectors, with $(\varphi^k > \varphi^l)$.

[14] L^k and L^l are the zero-growth-rates points for sector k and l. Since$(\varphi^k > \varphi^l)$, L^k is greater, in absolute value, than L^l.

$$\sum_{l=1}^{m} w^{jl}\frac{\dot{y}^l}{y^l}=\frac{\dot{y}}{y}+\mathrm{Cov}_z^j\,(d^{j,\cdot},\frac{\dot{y}^l}{y^l}) \quad \text{and} \quad \sum_{l=1}^{m} w^{jl}\bar{h}_S^l=\bar{\bar{h}}+Cov_z^j(d^{j,\cdot},\bar{h}_S^l) \tag{15}$$

sectoral output growth then becomes:

$$\frac{\dot{y}^j}{y^j}=\left(\frac{f^j\varphi^j+\bar{d}_z^j}{f^j+\bar{d}_z^j}\right)\frac{\dot{y}}{y}+\Delta^j\,(\bar{\bar{h}}-\bar{h}_S^j)+\Delta^j\left[\frac{\mathrm{Cov}_z^j(d^{j,\cdot},\dot{y}^l/y^l)}{f^j}+Cov_z^j(d^{j,\cdot},\bar{h}_S^j)\right] \tag{16}$$

The first point to be emphasised is that the construction of the average of the distribution of sectoral unit costs and output dynamics Eq. (15) reflects the underlying theory of co-ordination and competition. In order to understand sectoral dynamics it is necessary to represent the moments of the distribution in a way which is economically meaningful. This model of selection suggests that the average values of the population should be weighted with the coefficients d^{jl} of product substitutability in order to be able to represent the interdependent dynamics of industries.

Moreover the use of w^{jl} as weights emphasises that the rate of growth of sector j depends positively upon the covariance between the values of product substitutability for sector j and, on one side, the sectoral growth of output and, on the other, sectoral average unit costs.

This suggests the second point to be stressed. Adding an important level of heterogeneity, that is allowing for the possibility that sectoral connections differ on the demand side in term of degree of substitutability, implies that sectoral output growth is affected by the specific combination of the sectoral features expressed in the covariance terms. It is not only important, as in Eq. (13), the institutional framework in which selection and sorting take place and their characteristics, but also the specific position that a sector occupies in the whole economy in terms of product characteristics and substitutability and the performance in terms of size, growth and unit costs of substitute sectors. As a result this model shows that a sector grows faster if it is 'closer' to sectors with relatively higher output growth and to sectors with relatively higher average unit costs. On the contrary if consumers find it easier to substitute sector j products with goods from other sectors with relatively more efficient production processes, we observe an increased pressure on firms in sector j and accordingly lower rate of output growth.

Sectoral output growth is then importantly affected by the 'institutional' market variables and the degree of product substitutability embedded in the coefficient[15] d^{jl}. The intensity of the selection and sorting processes and the weight of the covariance terms depend on the 'cross-sectoral market selection coefficient' (Δ^j). Δ^j measures the selective pressure on firms of sector j, is sector-specific and is an increasing function of $\bar{d}_z^j$ and of the sector-specific features which affect the access to financial markets and the propensity to accumulate (f^j). $\bar{d}_z^j$ depends also on the number of coefficients d^{jl} which are different from

[15] d^j means that, in the covariance, j is held constant and the sum is implemented across l. It might be the case that some d^{jl} are zero. If d^{jl} have all the same values, $w^{jl}=z^l$ and the averages become weighted by sectoral market shares.

zero and, therefore, on the number of substitute sectors in the economy, and on their size. Moreover, and importantly, $\bar{d}_z^j$ is higher if high values of the proximity indexes are associated with substitute sectors that have a great share of the entire economy. As $\bar{d}_z^j$ varies over time according to the structural changes of the economy, Δ^j changes as well and increases if there is a gain in the share of the economy of the sectors twinned with high d^{jl}. For those sectors which observe a growth in $\bar{d}_z^j$, the relative position in terms of average unit costs becomes more important relative to the growth elasticity of sectoral demand.

For a high enough value of $\bar{d}_z^j$, a monopoly position within sector j is not 'safe' even if no new firms enter sector j. In the single-industry model (Section 3), a monopolist fixes the price to meet the exogenous growth of demand and its position is not in danger. Conversely, if there are substitute sectors in the economy the monopolist growth is jeopardised by the emergence and the development of more efficient sectors that can erode its share in the entire economy.

Structural change is then driven by the specific articulation of the different levels of heterogeneity in the economic system[16]. Uniform growth is only possible if we eliminate variety and sectors have all the same characteristics. In addition changes of average unit costs, within a population, depend on the population unit cost variances. If sector j is a monopoly, its average rate of unit cost decrease is zero. If it is not, even assuming that unit cost are constant at firm level (as it is assumed here), average unit costs continuously change because of the selection process within and across each industry. Hence it clearly emerges that the process of structural change and, in particular, sectoral selection, are driven also by the structures of populations of firms within each sector.

This model stresses only the transitional properties of a system in which the starting number of firms and sectors is given and variety is eroded, even if not completely because some sectors are independent and product substitutability is zero. In the long run the evolutionary process of structural change is nurtured by the emergence of new sectors and firms.

4.4. The evolutionary process within industries

We show that the properties of the evolutionary process within industries in Section 3 are a particular case of the general model presented here and that the new assumptions about the selection and sorting processes and product substitutability have not changed the properties of the evolutionary dynamics and competition within each sector.

[16] Variety relies ultimately on firms specific characteristics in terms of production processes and, in turn, unit costs. Although it assumed that firms produce different commodities in different sectors and, therefore, we have variety also in terms of product characteristics, we do not have a measure of the extent of product differentiation of the output of the system as a whole that has been used to assess the microeconomic impact on consumer welfare and the macroeconomic effect on patterns of international trade and growth.

Proposition 7. *The evolutionary selection process within each sector is the same as in Proposition 1, 2 and 3. In particular the rate of reduction of the population average unit cost depends on the variance of the population unit costs and it is positively related to the cross-sectoral market selection coefficient.*

The behaviour of the population of firms and, therefore, selection are governed by the same process as before, also when firms in sector j fix normal prices keeping into account average prices in all sectors. Still there is one important difference. All sectors are now intertwined in the process of structural change and, therefore, normal prices, firms' growth and conditions for exit reflect this circumstance.

Using (Eqs. (2), (7) and (8)), (see footnote 10) it can be shown that:

$$\frac{\dot{y}_i^j}{y_i^j}-\frac{\dot{y}_{\mathrm{D}}^j}{y_{\mathrm{D}}^j}=-\Delta^j(h_i^j-\bar{h}_S^j);\quad \Delta^j=\frac{f^j\bar{d}_z^j}{f^j+\bar{d}_z^j} \tag{17}$$

As explained above the market selection coefficient is sector-specific and is an increasing function of $\bar{d}_z^j$ and of the sector specific features which affect the access to financial markets and firms' propensity to accumulate (f^j). $\bar{d}_z^j$ depends on the amount of substitute sectors in the economy and on their size. The Fundamental Theorem now is:

$$\frac{\partial\bar{h}_S^j}{\partial t}=\sum\dot{s}_i^jh_i^j=-\Delta^j\sum s_i^j(h_i^j-\bar{h}_S^j)h_i^j=-\Delta^jV_S(h^j) \tag{18}$$

In the multi-sectoral context the Fundamental Theorem is particularly important because, as shown above, sectoral selection is based on relative average unit costs. As a result sectoral selection is driven by the unit cost variance within each sector. It is interesting to emphasise that, also in this generalised case, sectoral selection takes place through the zero-profit ceiling (Ψ^j). Sector j firms stay in the market if their unit cost is below the value of Ψ^j that, in a multi-sectoral economy, is:

$$hi^j<\Psi^j(\bar{h}_S^j)=\left[\frac{1}{\Delta^j}\right]\varphi^j\frac{\dot{y}}{y}+\bar{h}_S^j \tag{19}$$

Firms' ability to survive is affected by the structure of selection process across industries, through the value of Δ^j. The negative relation between Δ^j and Ψ^j displays the degree of selective pressure, due to cross sectoral competition, for a given rate of output growth and average unit costs. In particular Ψ is a negative function of $\bar{d}_z^j$. The competitive pressures on sector j firms increase with the number and the size of the sectors that have the d^{jl} coefficient greater than zero. As a result, firms are selected not only on the basis of their production routines but also in terms of the dynamic of the sectoral shares in the entire economy.

Chances to exit depend on the unit cost sectoral average. It is worthwhile to repeat that in all sectors unit cost weighted averages are decreasing along industry evolution because of the market share shift in favour of the more efficient firms. Consequently Eq. (19), like Eq. (5) in Section 3, expresses a ceiling which becomes increasingly binding as industries evolve. Finally Ψ^j is positively related to the output growth elasticity of demand of sector j. The influence of a change in φ^j is simple and works through the impact on the sectoral growth rate of demand. *Coeteris paribus* firms, which belong to high-income elasticity sectors, survive in the market with higher levels of unit costs.

In this section a general model of industrial evolution has been analysed in which market selection mechanisms bring together a variety of rival behaviour and destroy diversity not only within sectors, but also across sectors. Firm variety is grounded on the different production routines embedded in firms' organisational and technological traits. Sectoral variety emerges at three levels. First in terms of 'proximity' indexes, they differ in terms of degree of substitutability. Second in terms of different technological trajectories, which are expressed by the dynamic of sector-specific unit cost average. Finally in terms of income elasticity of demand. In this picture the creation of new firms and new sectors is left out. This is a relevant empirical fact, that misses in the picture and that constitutes a very important force of structural change (Saviotti, 1988, 1996). Nevertheless the mechanisms, through which small innovative firms gain market shares, are accounted for in this model.

5. Structural change and aggregate labour productivity

Once we have represented the economy as a process of continuous transformation generated by heterogeneity at micro level and co-ordinated by the selection and sorting processes, we show that at the aggregate level, rates of productivity growth are also affected by the specific characteristics of firms and sectors, and their specific combination. In particular if the competitive process within and between sectors brings about selection and structural change as outlined above, we expect the aggregate rate of productivity to grow because less efficient activities are driven out of the market. This is true unless sorting forces sustain the growth of sectors with higher unit costs.

In general we expect that selection process and the institutional settings in which it unfolds, combined with sorting, drives aggregate productivity growth. As a result at least a part of the Solow residual can be result of competition and selection and this cannot be grasped with theoretical frameworks which use the representative agent and the aggregate production function.

Let us assume that $f^j = f$ and $d^{jl} = d$. These assumptions reduce the degree of variety in the system. At the same time they greatly simplify the analysis and allow for a clearer understanding without changing the basic properties of the system. Variety at the aggregate level, then, arises from three dimensions, firm level unit cost distribution, sectoral level income elasticity and industrial average unit costs distribution.

Proposition 8. *The aggregate rate of growth of labour productivity (under the assumption that f^j and d^{jl} are the same for all sectors and all firms) is inversely proportional to the covariance between sectoral income elasticity of demand and average sectoral unit cost, and directly proportional to the variance of average sectoral unit cost and to the average of firm level unit cost variances within each sector.*

To enquire about the properties at the aggregate level of a process of sorting and selection within and between sectors we calculate the rate of decrease of the average level for the entire economy from Eqs. (13), (18) and (19), as follows [17].

$$\frac{\partial \bar{\bar{h}}}{\partial t} = \sum_{j=1}^{m}\sum_{i=1}^{nj}(\dot{z}^j s_i^j + \dot{s}_i^j z^j)h_i^j = \sum_{j=1}^{m}\dot{z}^j \bar{h}_S^j + \sum_{j=1}^{m} z^j \sum_{i=1}^{nj}\dot{s}_i^j h_i^j$$
$$= \Delta\left[\frac{1}{d}\frac{\dot{y}_D}{y_D}\mathrm{Cov}(\varphi^j, \bar{h}_S^j) - V_z(\bar{h}_S^j) - \overline{V_S^j(h_i^j)}_z\right] \tag{20}$$

with:

$$Vz(\bar{h}_S^j) = \sum_{j=1}^{m} z^j(\bar{h}_S^j - \bar{\bar{h}})\bar{h}_S^j$$

$$\overline{V_S^j(h_i^j)}_z = \sum_{j=1}^{m} z^j \sum_{i=1}^{nj} s_i^j(h_i^j - \bar{h}_S^j)h_i^j = \sum_{j=1}^{m} z^j V_S^j(h_i^j)$$

Moreover Eq. (29) can be transformed to express the aggregate rate of productivity growth.

$$\frac{\dot{\bar{\bar{q}}}_e}{\bar{\bar{q}}_e} = -\bar{\bar{q}}_e\Delta\left[\frac{1}{d}\frac{\dot{y}_D}{y_D}\mathrm{Cov}(\varphi^j, \bar{h}_S^j) - V_z(\bar{h}_S^j) - \overline{V_S^j(h_i^j)}_z\right] \tag{21}$$

This generalised version of Metcalfe's Fundamental Theorem tells us that aggregate economic evolution is driven by heterogeneity at a micro and meso level and by the process of structural change. If there is not variety, there cannot be economic change. It is worthwhile noting again that Proposition (8) describes a diffusion effect with no innovation at a firm level, no firm-level productivity gains and an exogenous rate of economic growth. Notwithstanding competition, selection and sorting drive a process of substitution among firms and sectors which, in turn, drives aggregate patterns of productivity growth. The structure of the populations of firms and sectors can guide aggregate productivity growth even without technical progress with given unit labour requirement at a firm level. In this respect it can be claimed that Eq. (21) defines a lower boundary for aggregate productivity growth. It could be higher including innovation and entry in the model.

Clearly a model which points at giving a full account of patterns of economic development and transformation should include a process of variety generation at both product and technological level. Variety increases in the course of economic development and the generation of new product and new production processes are an important component of pattern of productivity growth (Saviotti, 1994).

Structural change, here, is a process, which starts at a micro-level and is the outcome of competition and selection within sectors and competition, selection and sorting among firms in different sectors. Productivity growth is, then, the outcome of a market process of variety co-ordination. Variety, as well as co-ordination,

[17] At the aggregate level $\dot{\bar{\bar{q}}}/\overline{\overline{q_e}} = -\dot{\bar{\bar{a}}}/\overline{\overline{q_z}}$ and $\dot{\bar{\bar{q}}}/\overline{\overline{q_e}} = \overline{\overline{q_e h_z}}$. All variables represent economy-level averages. The weights are, according to the sub-scripts, z^j (industrial share of total output) or e^j (sectoral employment share of total output).

arises at different levels of aggregation. The understanding of the interaction between these different levels should be part of the explanation of aggregate patterns of growth. In this paper we show then that at least a portion of Solow's residual (Solow, 1957), which has often been measured as an aggregate and labelled '*technical change*', can be understood without technical change and, simply, as a result of a changing sectoral composition due to selection and sorting at micro level.

In particular sorting and selection play two different roles in the productivity growth. First if sectoral income elasticities of demand are all equal to one, $\mathrm{Cov}(\varphi^j, \bar{h}_S^j)$ drops to zero. So, if just selection occurs, the reduction of unit costs and the aggregate growth of labour productivity is guided by the dynamic of the variances within and between sectors. If this is not the case, the aggregate growth rate of labour productivity is inversely proportional to the covariance between sectoral elasticity of demand and sectoral average unit costs ($\mathrm{Cov}(\varphi^j, \bar{h}_S^j)$) and to the exogenous rate of demand growth. Hence sorting is not, in itself, an efficiency-improving process, if the sectoral distribution of income elasticity of demand pushes the economy towards the sectors with a relatively higher average unit cost, the rate of improvement of the average level of economic fitness slows down. Conversely it is an efficiency-improving process if the value of $\mathrm{Cov}(\varphi^j, \bar{h}_S^j)$ is negative.

Moreover the aggregate growth rate of labour productivity is proportional to $Vz(\bar{h}_S^j)$, the variance in sectoral unit costs in the economy, and to $\overline{V_S^j(h_i^j)_z}$ that is the average across sectors of the variances of firm level unit costs within each industry. This result confirms and generalises the Fundamental theorem at industry level (see Eq. (6), Section 3). An increase of variety both at sectoral and firm level (that is a greater dispersion of firms' behaviour and a greater diversity across industries) improves the rate of reduction of average unit cost. Conversely a system which is not able to generate variety is bound to declining productivity growth rate, because selection in the long run generates a reduction in the cross firm and cross sectoral unit costs variances.

Finally the size of the market selection coefficient (Δ) affects directly productivity growth rate. The intensity of the positive relation between variety and the rate of producivity growth is proportional to the value of d and f. Note that, at the same time, the partial derivative of $\partial\bar{\bar{h}}/\partial t$ on $\mathrm{Cov}(\varphi^j,\bar{h}_S^j)$ depends negatively on d. So a higher value of d improves market efficiency, enhances selection and reduces the partial impact of $\mathrm{Cov}(\varphi^j,\bar{h}_S^j)$ on the reduction of average unit costs and rates of growth of productivity.

6. Conclusions

Processes of structural change are a fundamental characteristic of economic development and a key component in accounting for the rate and direction of aggregate productivity growth, as emphasised by a long tradition in the history of economic thought (Fisher, 1939; Clark, 1940; Schumpeter, 1928; Kuznets, 1971;

Baumol, 1967; Pasinetti, 1981). However, it seems problematic to explain processes of structural changes, sector interdependence and transfer of resources across different industries using some standard assumptions of the new growth models (Aghion and Howitt, 1998).

This paper provides an attempt to analyse the determinants of structural change and aggregate productivity growth from the perspective of evolutionary economics. Moreover, it shows that some properties of the relationship between unit cost distribution and the dynamics market structures in a single industry hold when the analysis is extended to a multisectoral economy. In particular, this paper provides a consistent generalisation of the baseline replicator dynamic models of Metcalfe (1998), which focus only on a single industry.

This paper assesses the relationship between heterogeneity at firm level and structural change and claims that only under very restrictive conditions upon the parameters of the model, growth is a uniform process in which sectors expand at the same rate. Allowing for heterogeneity this paper shows analytically the determinants of structural change on the basis of a sorting process, which depends upon different income elasticities of sectoral demand (in the Pasinetti tradition), and on a selection process within and between sectors.

It shows that an understanding of structural change has to be grounded in a macroeconomic consistent aggregation mechanism reflecting the underlying theory of sorting and selection. In this respect this paper argues that the weighting scheme used in the aggregation should take into account the degree of substitutability among products.

Moreover, it shows that the combined effect of selection and sorting on sectoral output growth depends upon the institutional characteristics of the evolutionary environment. As higher product substitutability increases the selection pressure, sorting is less important as a determinant of structural change. Selection effects, based on deviations from the population average unit cost, depend positively on the value a market selection coefficient, which takes into account sectoral proximity in terms of visibility and knowledge dispersion about rival offers and consumers' perception of different levels of product quality. Uniform growth turns out to be a very special case in which unit costs do not vary across sectors and either growth elasticities of sectoral demand are uniform across sectors or cross-sectoral substitutability is infinite.

At the same time, it is not only the institutional framework, in which selection and sorting take place that is important. The specific position that a sector occupies in the whole economy in terms of product characteristics, substitutability and the performance in terms of output size, growth and unit costs of substitute sectors also plays a significant role. As a result, this model shows that a sector grows faster if it is 'closer' to sectors with relatively higher output growth and to sectors with relatively higher average unit costs.

Finally, if growth is non uniform the specific institutional characteristics of countries and the typology of specialisation is expected to affect importantly aggregate patterns of productivity growth. Accordingly we show that the selection process and the institutional settings in which it unfolds, combined with sorting, guide the growth of aggregate productivity, which can display positive values without technological change at firm level and as a result of competition and selection processes between heterogeneous agents. At least a part of the Solow residual can be conceptualised as a result of selection and structural change and this cannot be grasped using the representative agent and the aggregate production function.

In particular, we have shown that the aggregate growth rate of labour productivity depends negatively upon the covariance between the sectoral elasticities of demand and the sectoral average unit costs. This means that sorting is not, in itself, an efficiency-improving process. Moreover the aggregate growth rate of labour productivity depends positively on the exogenous rate of demand growth and is proportional to the variance between sectoral unit costs and to the average of firms' unit cost variances within sectors (Here this paper provides a generalisation of the Metcalfe's Fundamental Theorem to the aggregate economy). This result emphasises that aggregate economic evolution is guided by heterogeneity at a micro and industrial level and by the specific combination of the characteristics of the different interdependent industries.

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Appendix A

Eq. (2) is the result of the following, $\mathrm{TP}_i = (p_i - h_i)y_i$ is the total profit of firm i. The total amount of investement is financed from two sources, from internal sources as a share of total profit and from external sources. Therefore, if $\mathrm{IP}_i = \pi_i \mathrm{TP}_i$ is the amount of total profit which is invested by firm i, investment is:

$$\dot{K}_i = I_i = \mathrm{IP}_i + \mathrm{EF}_i = \pi_i(p_i - h_i)y_i + \mathrm{EF}_i \tag{A.1}$$

EF_i is the total amount of external financing. Assume that $\mathrm{EF}_i = \varepsilon_i \mathrm{IP}_i$ then Eq. (A.2) can be rewritten as:

$$\frac{\dot{K}_i}{K_i} = \left[\frac{\pi_i(1+\varepsilon_i)}{c_i}\right](p_i - h_i) \quad \text{with} \quad c_i = \frac{K_i}{y_i} \tag{A.2}$$

It has to be noted that we assumed that $c_i = b$ and, therefore, this also implies that $\dot{K}_i/K_i = \dot{y}_i/y_i$.

The parameter $f_i = [\pi_i(1+\varepsilon_i)/c_i]$ depends on the invested proportion of internal profit and on the amount of external financing expressed in terms of a fixed share of the internal investment (IP_i). This discussion shows that the assumption that f is the same for all firms implies important restrictions on π_i, ε_i and c_i. Moreover it is assumed that $c_i = b$ is constant: firm i's output growth is driven by the growth in the capital stock which turns out to be a fixed proportion f of the unit profit margin.

Eq. (3) relies on the assumption that market share growth of firm i depends upon the consumers' comparison of the different prices set by all firms and by the visibility of firms expressed in terms of market share. In particular it is assumed that:

$$\dot{s}_i = \sum_j s_i s_j \delta (p_j - p_i) = s_i \delta \sum_j s_j (p_j - p_i) = s_i \delta (\bar{p}_s - p_i) \tag{A.3}$$

Eq. (3) follows on the basis that firm i is always able to produce the demanded output and noting that:

$$\dot{s}_i = s_i \left(\frac{\dot{y}_i}{y_i} - \frac{\dot{y}}{y} \right)$$

In Eq. (A.3), a unique δ for all firms is assumed. Here we show that the selection equation (Eq. (3)) is appropriate also for specific δ_{ij} for each interaction between firm i and j. Moreover we stress that, in this case, the assumption that the matrix $\mathbf{D} = [\delta_{ij}]$ is symmetric is a convenient and economically consistent restriction. Relax, than, the restrictions on δ and consider δ_{ij}.

$$\dot{s}_i = s_i \left(\frac{\dot{y}_i}{y_i} - \frac{\dot{y}}{y} \right) \quad \text{and} \quad \dot{s}_i = s_i \sum_j s_j \delta_{ij} (p_j - p_i)$$

The selection equation now is:

$$\frac{\dot{y}_i}{y_i} = \frac{\dot{y}}{y} + \sum_j s_j \delta_{ij} (p_j - p_i)$$

Applying the weighted average using firms' market share it becomes:

$$\sum_i s_i \frac{\dot{y}_i}{y_i} = \frac{\dot{y}}{y} + A$$

$$A = \sum_i s_i \sum_j s_j \delta_{ij} (p_j - p_i) = \mathbf{s}' \{ \mathbf{DP} - \mathbf{PD} \} \mathbf{s}$$

s, the vector of firms' market shares ($n \times 1$); **D**, the matrix of δ_{ij} ($n \times n$); **P**, the diagonal matrix with all prices on the diagonal ($n \times n$).

A is zero if $\mathbf{D} = \mathbf{D}'$ that is if $\mathbf{D}$ is symmetric. Using the distributive property of the product, A is the difference of two scalars, $A = \mathbf{s}'\mathbf{DPs} - \mathbf{s}'\mathbf{PDs}$. Since $\mathbf{P} = \mathbf{P}'$ and $\mathbf{D} = \mathbf{D}'$ we can write $A = \mathbf{s}'\mathbf{DPs} - \mathbf{s}'\mathbf{P}'\mathbf{D}'\mathbf{s}$. One is the transpose of the other and since they are two scalars they are the same and their difference is zero.

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