PRODUCTIVITY AND STRUCTURAL CHANGE: A REVIEW OF THE LITERATURE

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Abstract. This paper is a survey of the existing research on structural change at various levels of aggregation with a special focus on the relation to productivity and technological change. The exposition covers the research concerning the development of the three main sectors of the private economy, multisector growth models and recent evolutionary theories of structural change. Empirical studies of the reallocation of market or sector shares as a result of differential productivity developments are also discussed. The synthesis emphasizes the crucial interaction of supply- and demand-side forces in shaping structural change.

Keywords. Structural change; Productivity growth; Industrialization

1. Introduction

Structural change is understood in the work surveyed in this paper as 'long-term changes in the composition of economic aggregates' as defined by the Austrian economist Erich Streissler (Streissler, 1982, p. 2; author's translation). Two aspects of this definition are important. First, structural change is associated with changes that affect disaggregate units. These changes are generally of different magnitude for each single unit, since otherwise the composition of the aggregate would not change. Second, these differential changes are relevant in the long run, making structural change an important aspect of economic growth. Taken together, structural change in the economy implies that some industries or sectors experience faster long-term growth than others, leading to shifts of the shares of these industries or sectors in the total aggregate.

A very important contributor to our knowledge about structural change and its driving forces is Simon Kuznets who summarized his findings in his Nobel lecture given in 1971. There, Kuznets (1973, p. 250) states that

> rapid changes in production structure are inevitable – given the differential impact of technological innovations on the several production sectors, the differing income elasticity of domestic demand for various consumer goods, and the changing comparative advantage in foreign trade.

With this statement Kuznets points to two of the central causes of structural change that are still relevant in the more recent theoretical literature on the topic, i.e.

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varying income elasticities of demand and the differential impact of technological progress.

In a more recent contribution, Baumol *et al.* (1989) observe the great diversity of productivity developments across industries and sectors and emphasize not only the fact that structural change is a long-term phenomenon, but also that productivity growth is particularly relevant in the long run. They observe that 'for the entire postwar period there is simply no common pattern in the growth performance of the individual sectors and subsectors of the American economy' (Baumol *et al.*, 1989, p. 81). This diversity is also a widespread empirical finding in the literature on firm growth, entry and exit (Caves, 1998) and the role of productivity growth in that process (Bartelsman and Doms, 2000).

The topic of structural change is frequently neglected in economic research, despite its high relevance for growth theory, business cycle theory and labor market theory as well as for economic policy. Admittedly, to date there exists no general theory of structural change, but there exist a variety of theoretical approaches that are concerned with the explanation of structural shifts between the three broad sectors of the private economy and among the industries within these sectors. These theoretical approaches have their roots in appreciative verbal theorizing, modern formal economic growth theory and evolutionary innovation theory. The research covered by this survey satisfies two essential requirements. First, it deals with mostly theoretical research on industrial structure and its change in a dynamic context. Second, productivity improvements resulting from innovation and technological change are considered as one of the major driving forces of structural change.

These requirements preclude the coverage of other branches of economic research that are more remotely related to structural change as it is understood here.[1] This applies to general equilibrium models which provide a logically consistent determination of prices and quantities in all markets simultaneously (see Mas-Colell *et al.*, 1995, part 4)[2] but are mostly static competitive equilibrium models with only a rudimentary treatment of the production side and no analysis of the generation of innovations and the effects of technological change. Multisector endogenous growth models making use of the general equilibrium framework are an exception and will be discussed later in this survey. For similar reasons, the theoretical and empirical analysis of demand systems is also neglected (see e.g. Deaton, 1986; Blundell, 1988). Despite the fact that dynamics arising from product and process innovations receive a prominent treatment in the literature on the industry life cycle (see e.g. Audretsch, 1995; Klepper, 1996, 1997, 2002; Agarwal, 1998; Agarwal and Audretsch, 2001), this research is also not considered in this survey since it is concerned with the explanation of characteristic patterns in the number of firms within an industry. This lets the life cycle approach be very specific to the explanation of intra-industry structural change and it is, moreover, not universal across all industries (Klepper, 1997, p. 174). Although stage theories of economic development *à la* Rostow (1971) attribute an important role to sectoral shifts, they are specific to the field of development economics and are therefore not discussed here. The same applies to other work dealing with structural change in developing countries (see Syrquin, 1988).

This survey paper brings together very different strands of literature that are dealing with the relation of productivity and structural change at various levels of aggregation. These comprise the research on the regular pattern of the shifts among the agricultural, manufacturing and service sectors postulated by the three-sector hypothesis (Section 2), neoclassical multisector growth models (Section 3), theories of structural change in evolutionary tradition (Section 4) and empirical studies of reallocation and its relation to differential productivity developments (Section 5). The synthesis of this survey shows that structural change is shaped by the interaction of differential technological developments on the supply side with demand-side factors (Section 6).

2. The Three-Sector Hypothesis

Under the heading of the three-sector hypothesis, the long-run development of the three main sectors of the private economy is investigated at a highly aggregate level. This research is concerned with the successive dominance of the so-called primary, secondary and tertiary sectors in terms of employment and value added of an economy. The primary sector comprises agricultural and related activities, required to satisfy the basic needs of a society as well as the exploitation of natural resources. The secondary sector produces consumption and investment goods by combining raw materials and investment goods in addition to labor. It thus comprises mainly economic activities related to manufacturing and construction. The tertiary sector provides services such as banking and insurance that are generated primarily by the commitment of labor but also by using capital goods such as buildings and computers.

2.1 *Empirical Account*

The three-sector hypothesis postulates a systematic succession of the development of the three main sectors of the private economy. Initially, the primary sector is dominant, with respect to both the portion of people employed and the fraction in total value added. At this stage, the secondary sector and the tertiary sector account for only a small part of total employment and value added. With the advent of industrialization the secondary sector begins to gain in importance at the expense of the primary sector while the tertiary sector stagnates. Even later in economic development, labor and value added begin to shift from the primary and secondary sectors towards activities in the tertiary sector. In the end the majority of people are employed in the tertiary sector in which also the bulk of value added is generated. Figure 1 shows the development postulated by the three-sector hypothesis in a stylized way (note that the ordinate denotes the cumulated shares of the three sectors either in terms of employment or in terms of value added).

This pattern of sectoral development has first been observed by Fisher (1939). For the USA and various other economies it is systematically explored and documented in the work of Kuznets (1957, 1966, chapter 3). Kongsamut *et al.* (2001) review this empirical pattern of sectoral development using US sectoral employment shares

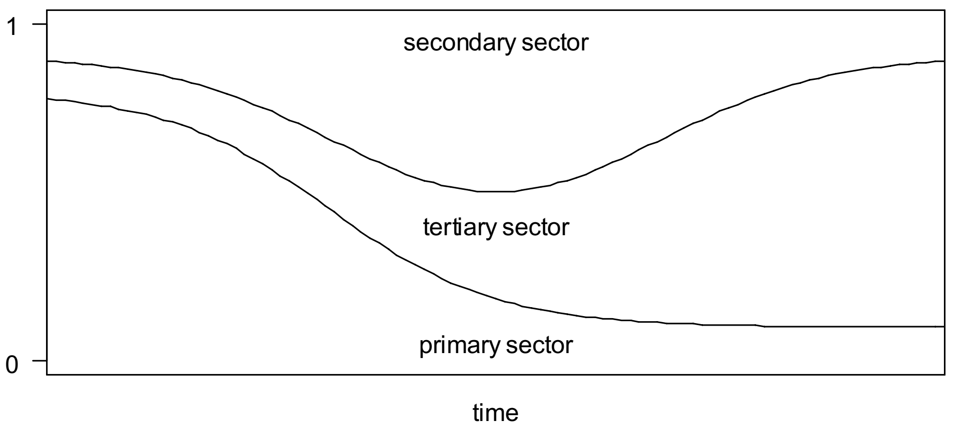

Figure 1. The Three-Sector Hypothesis.

during 1869–1998 and consumption shares during 1940–1999. They term these empirical regularities the Kuznets facts in analogy to the stylized facts established by Kaldor (1961) for aggregate magnitudes. In his Nobel lecture, Simon Kuznets summarized the development in many countries up to the 1960s as the third of his six characteristics of modern economic growth, stating that

> the rate of structural transformation of the economy is high. Major aspects of structural change include the shift away from agriculture to nonagricultural pursuits and, recently, away from industry to services. (Kuznets, 1973, p. 248)

The following illustration continues Kuznets's descriptive statistical account of the development pattern postulated by the three-sector hypothesis for the US private economy during the period 1948–2000.

The data used are taken from the US economic accounts provided by the Bureau of Economic Analysis, relying on the standard industrial classification (SIC) of 1987.[3] In this classification, the primary sector consists of agriculture, forestry, fishing and mining industries (SIC 01–14 at the two-digit level). The secondary sector consists of all durable (SIC 24, 25, 32–39) and nondurable (SIC 20–23, 26–31) goods manufacturing industries. The construction industries (SIC 15–17) are usually treated as part of the secondary sector, but in many studies the secondary sector is confined to manufacturing (SIC 20–39). Treated as parts of the tertiary sector are transportation and public utilities (SIC 40–42, 44–49) including communications services (SIC 48), wholesale and retail trade (SIC 50–59), finance, insurance and real estate (SIC 60–67) and services (SIC 70–89). The services category includes hotels, auto repair and motion pictures as well as personal, business, health, legal, educational and social services together with private households.

Figure 2 shows the time paths of the sector shares in the total private US economy. Two kinds of shares are considered: value-added shares defined as the shares of each

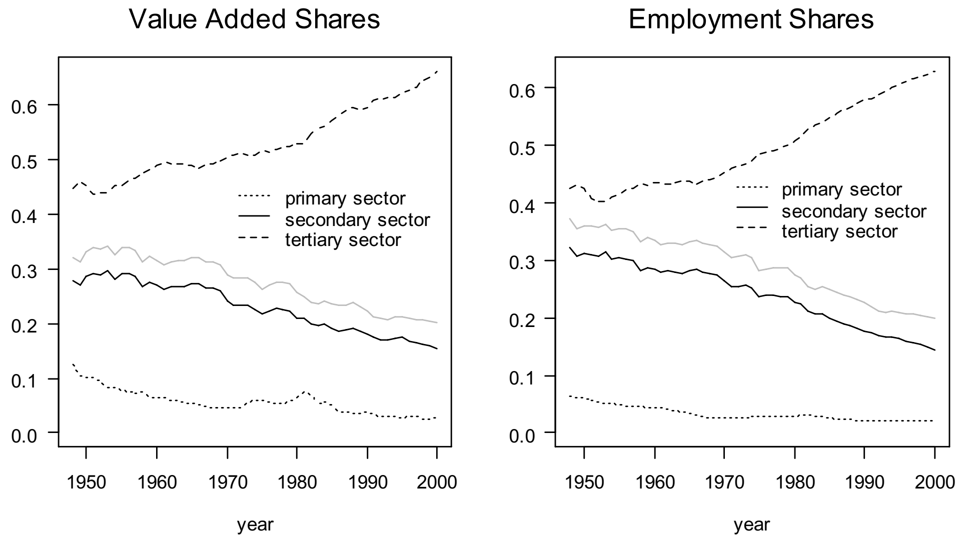

Figure 2. Sector Shares in the US Private Economy (Bureau of Economic Analysis, US Economic Accounts).

of the three sectors in total value added (current dollar GDP of the private economy), and the employment shares, defined as the share of each sector in full-time equivalent employees of the private economy.

The development during 1948–2000 starts with the situation where the primary sector has already declined to slightly above 10% of value added and less than 10% of employment of the private economy, and where the tertiary sector is already the dominant sector in terms both of value added and of employment. The secondary sector's share declines steadily during the period. The solid black line shows the share of the secondary sector when comprising only the manufacturing industries. The solid gray line represents the share of the secondary sector including the construction industries which closely follows the development of manufacturing. Also clearly visible are the weakly declining share of the primary sector and the rapidly growing share of the tertiary sector. Comparing value-added and employment shares, the figure reveals that their development is very similar. This pattern is not limited to the US economy but applies more generally to most developed countries. Broader international evidence to support the tendency of a declining secondary sector and an increasing tertiary sector in terms of labor force shares is discussed in Baumol *et al.* (1989, chapter 6).

Along the same lines, Nelson and Wright (1992) provide a thorough analysis of the technological development in the USA relative to other countries during the period ranging from the end of the nineteenth to the end of the twentieth century. They argue that the long-standing US lead was based on two major factors: first, its comparative advantage in mass production due to its large natural resource base and large domestic market; second, its high-technology manufacturing industries whose strength stems from investments in higher education and the effective use of the resulting skills by firms as well as by industrial research and development. Both of these comparative strengths of the US economy have been increasingly eroded since the end of World War II. These developments were accompanied by a substantial reduction of the share of the US manufacturing sector as shown in this section.

2.2 *Theoretical Explanations*

Initially, the theoretical literature on the three-sector hypothesis was concerned with the discussion of different criteria for the classification of the primary, secondary and tertiary sectors that lead to potentially different theoretical explanations for the development outlined above. Fisher (1939) divides the sectors according to a hierarchy of needs, starting with goods that satisfy basic needs in the primary sector, standardized products in the secondary sector (especially manufacturing), and new products in the tertiary sector. Fisher (1952, p. 828) associates the three sectors with an increasing income elasticity of demand for their respective products. Clark (1957) undertakes a purely enumerative listing of industries based on common characteristics and assigns agriculture, forestry and fishery to the primary sector, all goods producing and processing industries to the secondary sector and the remaining industries to the tertiary sector. The latter industries consist of construction, transport, communication, finance, public administration, personal services, etc. Wolfe (1955) collates industries with the same dominant factor of production that promotes their growth. Accordingly, industries which rely mainly on natural growth factors are assigned to the primary sector, industries which rely mainly on mechanical growth factors are assigned to the secondary sector, and industries which rely mainly on human skills are assigned to the tertiary sector. These dominant factors are assumed to be responsible for the limitation of the increase of labor productivity in the respective sectors. Fourastié (1949/1969), finally, relies on technological progress, operationalized by the growth rate of labor productivity, as the central classification criterion. In his classification, industries with a medium rate of technological progress are assigned to the primary sector whereas industries with a relatively high rate of technological progress are assigned to the secondary sector. The remaining industries with a relatively low rate of technological progress are considered as part of the tertiary sector.[4]

Of the theoretical explanations for the development pattern postulated by the three-sector hypothesis given in this literature, the explanation by Fourastié (1949/1969), published in the French and German languages, is the most complete and compelling.[5] Therefore it merits a more detailed discussion. Fourastié develops a broad theory of economic development involving psychological and sociological elements that supplement the economic considerations. In this context, a value theory of labor in which real labor costs are crucial for the determination of prices is an important element. With increasing labor productivity, real labor costs decrease which in turn permits price reductions. Considering that Fourastié assumes differential growth rates of labor productivity in the three sectors and further assuming sufficient competition, this mechanism leads to differential price trends across the three sectors. As a consequence, in the long run technological progress reduces rents and profits in all sectors, although with different force. According to Fourastié's view, the development of rents and profits determines the pace and direction of structural change of employment and output. Thus, the structure of relative prices, mediated by its effect on the development of rents and profits, determines the allocation of production factors among the sectors.

One result of these supply-side considerations is that sectors with a high rate of technological progress and labor productivity gain in importance whereas sectors with a low rate of technological progress and labor productivity lose ground and therefore suffer in terms of employment and value added. According to Fourastié's assumptions regarding the differential effects of technological progress in the three sectors, these considerations alone would imply a relatively small expansion of the primary, a relatively large expansion of the secondary and a decline of the tertiary sector. On the demand side, in contrast, it is assumed that the demand for primary sector goods is first saturated, followed later by increasing demand for secondary sector goods as real income per capita rises. This demand will eventually become saturated as well. In the case of the tertiary sector, it is assumed that demand will never be saturated as real income per capita increases. Fourastié further assumes that changes in relative prices and therefore process innovations which differentially increase labor productivity have no direct influence on the structure of demand.

Viewed against the empirical pattern of sectoral development, these considerations imply that in the long run the changes of the demand structure dominate the supply-side forces. According to Fourastié's theory, both elements interact in a way that technological progress with its effects on labor requirements of production and real income per capita is the driving force of structural change whereas the direction of structural change is determined by the demand side. The sequence of events leading from a society dominated by agricultural production to a service-dominated society can be imagined as follows (see especially Fourastié, 1949/1969, pp. 106ff.):[6]

- In the first phase of development, the primary sector dominates employment and production, while the secondary and tertiary sectors are only of minor importance. Such agricultural societies are relatively stable and resemble European societies well into the eighteenth century, where the division of the primary, secondary and tertiary sectors was roughly proportional to 80 to 10 to 10 with respect to both employment and value added.
- This is followed by an unbalanced transition phase in which industrialization sets in and the secondary sector gains in importance. This development culminated around the year 1900 and later on the rise of the tertiary sector begins. In this phase, structural change is very intense and broadly follows the pattern that Schumpeter (1942) described with his concept of creative destruction. Technological progress in the primary sector permits the nutrition and supply of a still growing population. Fewer and fewer people are needed for primary production because demand for primary goods is getting saturated. Simultaneously, labor requirements of the secondary

sector increase so that large-scale labor reallocations from the primary to the secondary sector can take place. Higher real income per capita and higher standards of living lead to increasing demand for manufacturing products until saturation sets in also in the secondary sector. Along with further increases of real income per capita, this leads to consumption shifts towards the products of the tertiary sector, which are assumed to be associated with a high income elasticity.[7] To generate these products the tertiary sector employs those workers who are set free by the secondary sector and the share of so-called white collar and brainworkers increases substantially.

- This phase of intense inter-sectoral structural change is followed by a second stable phase with tertiary sector dominance. Here, the division of the primary, secondary and tertiary sectors with respect to employment or value added is roughly proportional to 10 to 10 to 80.[8] This second stable phase, however, does not mean the end of structural change. As in the preceding transition phase, continuous intra-sectoral structural change is still taking place within each of the three sectors. As Figure 2 above illustrates, this last phase was not reached by the US economy until 2000.[9]

In Fourastié's theory, the interaction of demand-side and supply-side factors, i.e. saturation and technological progress, shapes the co-evolution of the three main sectors of the private economy. The decline of the primary and the rise of the secondary and tertiary sectors are clearly evident. The final transition to a service society, however, requires that the secondary sector (i.e. manufacturing) accounts for only a minor share of employment and value added. The argument for a saturation of needs for goods of the secondary sector in particular is not totally compelling since many manufacturing products (i.e. durable and investment goods) are intermediate inputs which are used in all three sectors. Thus, even if there were a saturation in final consumption goods of the secondary sector, this does not automatically imply a declining share of the secondary sector in total value added. The share of employment in the secondary sector may still decline because of further increases in mechanization and the comparatively higher rate of technological progress in this sector. This issue is analyzed by Baumol (1967) in the framework of a highly stylized model which will be discussed next.

Baumol (1967) focuses on the situation of unbalancedness in the transition phase. To this end, he introduces two sectors, one technologically progressive sector and one technologically stagnant sector with 'only sporadic increases in productivity' (Baumol, 1967, p. 416). It is assumed that the former resembles manufacturing, whereas the latter is more akin to services. Formally, in the case of labor as the single relevant input factor, output in the stagnant sector (indexed by s) and in the progressive sector (indexed by p) is specified as

$$Y_s = aL_s \quad \text{and} \quad Y_p = bL_p e^{gt}$$

respectively, where the total labor input $L = L_s + L_p$ is in some way divided between the two sectors.[10] Furthermore, a and b are assumed to be positive constants, g denotes the constant rate of labor productivity growth in the progressive sector, and e is the base of the natural logarithm. Note that labor productivity in the stagnant sector is constant over time. Nominal hourly wages in both sectors are the same and grow with the rate of labor productivity growth in the progressive sector, so that $w = e^{gt}$ (up to a negligible constant factor).

Unit costs of production are thus given by

$$c_s = wL_s/Y_s = e^{gt}/a \quad \text{and} \quad c_p = wL_p/Y_p = 1/b$$

and consequently their ratio is equal to $c_s/c_p = (b/a)\cdot e^{gt}$, so that relative unit costs of the stagnant sector grow without bound in the course of time. The reason is that because of the rising wages, technological progress in the progressive sector adds to the cost in the stagnant sector. Since prices always correspond in some way to unit costs (e.g. most directly if they are set by a constant markup upon unit costs), this dynamic immediately affects the price ratio of the two sectors.

If a constant output ratio of the two sectors is to be preserved it is immediate, from rearranging

$$Y_s/Y_p = (a/b) \cdot L_s/\left(L_p e^{gt}\right) \Rightarrow (b/a) \cdot Y_s/Y_p = L_s/\left(L_p e^{gt}\right) = k$$

where k is a positive constant, that this requires an ever-increasing transfer of labor from the progressive to the stagnant sector. Solving for the quantity of labor input and taking into account $L = L_s + L_p$ it follows that

$$L_s = k(L - L_s)e^{gt} = kLe^{gt}/(1 + ke^{gt}) \quad \text{and} \quad L_p = L - L_s = L/(1 + ke^{gt})$$

In the case of a rising instead of a constant output share of the stagnant (service) sector, the amount of labor transfer from the progressive (manufacturing) sector has to be even greater. In the limit as t tends to infinity, the labor share of services tends to unity and the labor share of manufacturing tends to zero. The output growth rate of the aggregate economy will approach zero in the limit. Of course, the limiting states are of little practical interest, but they highlight the general tendencies explained by the model.

The empirical evidence compiled by Baumol *et al.* (1985, 1989, chapter 6) shows that during the period 1947–1976 employment and prices in the stagnant sector have increased more rapidly than in the progressive sector whereas the real output shares remained roughly constant. Hence, these results can be viewed as a formal support for Fourastié's reasoning that the differential rates of productivity growth of manufacturing and services are associated with a large-scale labor reallocation towards the tertiary sector.

Against this strong prediction several reservations have been raised in the literature. Baumol *et al.* (1985) for example recognize that not all activities in the service sector are stagnant, but that there exists a subclass of progressive service activities that are called asymptotically stagnant.[11] These are characterized by both progressive and stagnant components, with the latter eventually becoming dominant. Nevertheless, progressive services are very similar to progressive manufacturing industries and may even show higher rates of productivity growth. As examples for asymptotically stagnant activities, the cases of electronic computation and television broadcasting are emphasized. Williamson (1991, p. 60) points out that part of the evidence may be ascribed to a flawed approach to measuring productivity and to the fact that most services are nontradables. Gundlach (1994) introduces iso-elastic demand equations into the model and claims that the stylized facts of structural change can only be explained if the demand for services is income elastic in addition to the differences in productivity growth.[12] Moreover, Oulton (2001) shows that Baumol's (1967) stagnation result crucially depends on the assumption that the stagnant industries produce final products. The result does not hold when services with a low rate of productivity growth serve as intermediary inputs to the manufacturing sector, as they frequently do in practice. Under certain circumstances the aggregate productivity growth rate may then even rise rather than fall.

In addition to the appreciative theorizing by Fourastié and the rather crude mechanical formal considerations by Baumol, there is also a branch of growth theory that provides more elaborate explanations for the particular pattern of the differential development of the three sectors that is postulated by the three-sector hypothesis. Leading examples of growth models dealing with differential sectoral development are Echevarria (1997), Laitner (2000) and Kongsamut *et al.* (2001). These models are discussed in the next section in the context of multisector growth models.

3. Multisector Growth Models

Neoclassical economic growth theory also addresses structural change, even though it has some difficulty with properly integrating heterogeneous sectors in its framework. Meanwhile, a number of models exist that are directly aimed at explaining the development pattern postulated by the three-sector hypothesis. These models are cast in the framework of growth models with exogenously given rates of technological progress and nonhomothetic preferences[13] which provide the crucial ingredient to generate sectoral shifts. Other models are not limited to just two or three sectors but in the most extreme cases deal with a continuum of infinitely many sectors. These general multisector growth models, however, always treat the sectors as symmetric after a certain stage of analysis. This symmetric treatment of sectors dates back at least to von Neumann (1945) but essentially eliminates the phenomenon of structural change from the analysis. Studies such as Siebert (1977), which is a simple comparative static analysis of a general equilibrium model with two sectors, will not be discussed in detail.

3.1 *Models Related to the Three-Sector Hypothesis*

As alluded to above, the models by Echevarria (1997), Laitner (2000) and Kongsamut *et al.* (2001) are specifically designed to explain the development pattern postulated by the three-sector hypothesis. They all build on the standard general equilibrium framework of growth models according to Solow (1956), Ramsey (1928), Cass (1965) and Koopmans (1965), in which nonhomothetic preferences are integrated. These preferences are driving the changes in the sectoral composition. In addition, it is assumed that the rates of technological progress in the three sectors (or the two sectors in the case of Laitner (2000)) are exogenously specified.

Echevarria (1997) constructs a three-sector model in discrete time in which the factor intensities and the rates of technological progress differ across the three sectors. The population, and therefore the labor input, is constant and capital is produced in the secondary sector and distributed to the other sectors. The model features an equilibrium growth path that converges to a limit where the labor input in the three sectors is constant and the consumption quantities grow at different rates in each sector. Simulations with the calibrated model reveal that aggregate growth is affected by the sectoral composition of the economy and vice versa. Structural change occurs in rough accord with the pattern of the three-sector hypothesis. The dynamics show that asymptotically one sector dominates the whole economy. The shares of the other sectors decline, although all sectors continue to grow in absolute terms. The dominant sector, however, is not necessarily the one with the highest rate of exogenous technological progress.

Laitner (2000) analyzes an economy consisting of two sectors: agriculture and manufacturing. For the agricultural sector, land is an important factor of production as is capital for the manufacturing sector. Over time, land becomes less important, capital accumulation becomes more important, and the average propensity to save rises. Technological progress raises income over time, and Engel's law causes demand to shift towards the manufacturing good due to the nonhomothetic preferences. In the limit, the share of agriculture in total GDP tends to zero and the share of manufacturing converges to unity.

Kongsamut *et al.* (2001) model a three-sector economy in a continuous-time general equilibrium framework with a common rate of exogenous technological progress and nonhomothetic preferences. The paper introduces the concept of a generalized balanced growth path on which the real interest rate is constant whereas the sector shares are permitted to grow differentially. In particular, the labor share of services grows, the labor share of agriculture shrinks and the labor share of manufacturing stays constant. Because of the specification of the sectoral production functions, these employment shares coincide with the respective output shares. A weakness of the model is that the generalized balanced growth path requires the validity of a knife-edge condition for its existence.

In all the models reviewed in this section, technological progress is assumed to be exogenous. Productivity may grow at the same rate in all sectors as in Laitner (2000) and Kongsamut *et al.* (2001) or different rates of technological progress across sectors may be specified as in Echevarria (1997). The inherent deficiency of assuming exogeneity of technological progress is addressed in endogenous growth models with multiple sectors. These will be discussed in the following section.

3.2 *General Multisector Growth Models*

There exist a variety of multisector endogenous growth models in which the number of sectors[14] is not limited to two or three but can be an arbitrary number or even a continuum. Prominent examples are Aghion and Howitt (1992), Grossman and Helpman (1991) and Romer (1990) which are the seminal papers of what has later been called Schumpeterian growth theory. Generally, in each of the sectors different intermediary goods are produced which are subsequently assembled to a final good. In these models either the number of sectors (and thereby the number of different intermediary goods available) or the quality of the intermediary goods (and thereby their productivity in the production of the final good) increases as a consequence of innovative activity. Both effects lead to rising total factor productivity at the aggregate level. Other models combine the increasing number of sectors with the aspect of quality improvements in these sectors in order to eliminate a rather unreasonable scale effect (see for example Aghion and Howitt (2005), Jones (1999) and Kortum (1997) for a more detailed discussion).

The multisector endogenous growth model of Aghion and Howitt (1998, chapter 3) is relatively general and will be described here in more detail since it clearly reveals the deficiencies of this type of model for the analysis of structural change.[15] In the model, a final good Y_t is produced competitively under constant returns to scale by combining a fixed amount of labor L and a continuum of independent differentiated intermediate goods x_{it}, where i is out of the interval [0, 1]:

$$Y_t = L^{1-\alpha} \cdot \int_0^1 A_{it} x_{it}^{\alpha} di \quad 0 < \alpha < 1$$

Here A_{it} denotes the productivity of intermediate good i. The final good can be alternatively used for consumption C_t, investment in capital goods I_t or as research input N_t, giving $Y_t = C_t + I_t + N_t$. The production of each unit of the intermediate good x_{it} requires the input of $A_{it}x_{it}$ units of capital, making newer technologies with larger A_{it} more capital intensive. Firms in the intermediate goods sectors act as monopolists who borrow money in order to pay for the input from the households which have to be remunerated at the rental rate ζ_t. Profit maximization gives

$$x_{it} = L \cdot \left(\zeta_t / \alpha^2\right)^{1/(\alpha-1)}$$

implying that all intermediate goods sectors produce the same amount of output and therefore the absence of structural change. Since this implies that $x_t = x_{it}\ \forall i \in [0, 1]$, the aggregate capital stock as the sum of the capital inputs across all sectors can be stated as

$$K_t = \int_0^1 A_{it} x_{it} di = A_t x_t \quad \text{where} \quad A_t = \int_0^1 A_{it} di$$

This allows us to solve for the rental rate of capital $\zeta_t = \alpha^2 (K/AL)^{\alpha-1}$. Recalling that $0 < \alpha < 1$, this implies that a higher capital intensity reduces the rental rate of capital.

In each intermediate goods sector a Poisson process controls the appearance of productivity-enhancing innovations. The arrival rate of this Poisson process depends on the research input in the respective sector and a research productivity parameter $\lambda > 0$. Once an innovation in any sector occurs, the productivity level of this sector immediately jumps to the 'leading-edge' productivity level $A_t^{\max} = \max_{i \in [0,1]}\{A_{it}\}$ which is available to all sectors in the next period and grows at the rate

$$d \ln A_t^{\max} / dt = \lambda \left(N_t \middle/ A_t^{\max}\right) \cdot \ln \gamma$$

Here, $\gamma > 1$ denotes the size of an innovative step on the quality ladder, expressed as the constant factor by which each innovation increases the productivity level in the respective sector. Innovation in a sector can be imagined as the replacement of an earlier variant of the respective good and thus represents the Schumpeterian notion of creative destruction. In the model, a strong intertemporal technological spillover effect is at work, postulating that each innovation serves as the basis for other innovations in other sectors of the economy even though the current innovation can only be used by the generating sector. Moreover, the equation for the growth rate of the leading-edge productivity level shows that with rising technological sophistication (rising $A_t^{\max}$) an ever-increasing research input N_t is necessary to sustain a certain innovation rate.

The model is closed by the imposition of an arbitrage condition, which guarantees that both research and production activities are exercised, and by the assumption of a steady-state equilibrium which requires that all quantities grow at the same constant growth rate as the leading-edge productivity level. This model is a good example for a growth model in which capital accumulation and innovation are complementary processes which are both necessary for long-run aggregate growth. Capital accumulation raises capital intensity which, in turn, lowers the rental rate of capital. This increases profit in the intermediate goods sectors providing the incentive for innovation. Innovations themselves increase the leading-edge productivity level which prevents the otherwise inevitable decline of capital productivity and thus sustains the incentive for capital accumulation. This model, despite its focus on an economy with multiple sectors, is also a good example of a growth model that is useless for the analysis of structural change because of the simplifying assumption that all sectors are symmetric.[16]

Even more sophisticated is the model of Klette and Kortum (2004), a multisector endogenous growth model in which heterogeneous firms are innovating and growing or shrinking, thereby shaping the aggregate outcomes. The specific aim there is to construct a general equilibrium model that is elaborate enough to address a wide variety of stylized facts derived from firm-level empirical evidence. These stylized facts concern the relationship of R&D and innovative output (represented by patents and productivity), empirical regularities regarding the patterns of R&D investment and firm entry, exit, growth and the size distribution of firms as predicted by Gibrat's law. In the model, the economy is assumed to consist of a continuum of firms that produce differentiated goods. It is further supposed that consumers have symmetric logarithmic preferences for these goods. An immediate consequence of the latter assumption is that consumer expenditures are the same for each of these goods. Interpreting each differentiated good as the product of a specific sector, the outcome is again that all sectors produce the same quantity of output and grow at the same rate, leaving their shares in the total unchanged over time.

This is exactly the pattern that Harberger (1998) refers to as the 'yeast' process, an economy which expands very evenly, like yeast, and in which all industries and sectors grow at the same rate which precludes structural change. Harberger brings together widespread empirical evidence on structural change both at the sectoral and at the firm level, concluding that this evidence does not support the yeast process.

Instead, firms, industries and sectors grow in unpredictable ways due to a multitude of influences and are thus more akin to the behavior of mushrooms. In his words, 'the "mushrooms" story prevails just as much among firms within an industry as it does among industries within a sector or broader aggregate' (Harberger, 1998, p. 11).

A notable exception to the symmetric treatment of industries is the multisector model constructed by Meckl (2002), building on the work of Kongsamut *et al.* (2001). The basis is a general multisector endogenous growth model with an increasing number of intermediate products. As in the models which aim at directly explaining the three-sector hypothesis, preferences are again assumed to be nonhomothetic. The analysis of the model shows that the concept of the generalized balanced growth path introduced by Kongsamut *et al.* (2001) can be extended to this more general framework. Thus, it holds true also for this more general framework that the balanced growth of aggregate magnitudes is compatible with structural change at the level of industries or sectors. However, in this model 'structural adjustment is only a by-product of economic growth that has no feedback on the growth process itself' (Meckl, 2002, p. 264). This stands in rather strange contrast to the Schumpeterian growth models discussed above. There, the process of creative destruction in which each intermediate product may be replaced by an innovation drives growth at the aggregate level, although associated with a constant sectoral composition of the economy by assumption.

Three further related models are worth discussing at this point: Acemoglu and Guerrieri (2006), Ngai and Pissarides (2007) and Foellmi and Zweimüller (2002). All of them show that, provided certain conditions hold, balanced growth at the aggregate level is consistent with structural change at the level of sectors. Acemoglu and Guerrieri (2006) analyze a two-sector model of economic growth. Their aim is to provide a supply-side explanation for structural change (similar to Baumol (1967)) based on differences in factor proportions together with capital deepening. Specifically, capital deepening increases the relative output in the sector with the larger capital share but simultaneously induces a reallocation of capital and labor away from that sector. This mechanism works without the imposition of nonhomothetic preferences. Important for most of the results of this paper is an elasticity of substitution below unity. A calibration exercise shows that the dynamics of the model are broadly consistent with US data. The principal findings also hold for an extension of the model to an endogenous growth setting with endogenous and directed technological progress.

Relatedly, Ngai and Pissarides (2007) also present a purely technological explanation of structural change. In their multisector growth model with many final consumption goods, sectors have identical production functions but differential exogenous rates of technological progress. For the case of low substitutability between final goods, employment is shifted away from sectors with high rates of technological progress along the balanced growth path. This result again parallels the main finding of Baumol (1967). Along the balanced growth path, employment in the sector with the lowest rate of technological progress expands and employment in the other sectors is either monotonically declining or hump shaped. By that, the model is able to explain the hump-shaped development of the manufacturing employment share as observed since the advent of the industrial revolution (see Section 2 above). By contrast, Foellmi and Zweimüller (2002) put more emphasis on the demand side in a model of endogenous growth and structural change. Firms in the model continuously introduce new products, but are identical in their labor requirements. As a result of the nonstandard utility specification, consumption across different goods expands along a hierarchy of needs. This leads to differential income elasticities of demand and induces demand-driven structural change.

In a rather different framework, Durlauf (1993) uses random field methods to model how technological complementarities across industries affect industry and aggregate dynamics. The industries are assumed to produce an identical good but use different production technologies which are subject to stochastic technology shocks. Each industry chooses between a high productive and a low productive technology depending on the choice of 'neighboring' industries. The interactions of the industries in the model can lead to multiple stochastic long-run (nonergodic) equilibria. The differences across the industries are summarized by a probability measure. The focus of Durlauf's analysis, however, is more on explaining aggregate output trends than on the dynamics of the contributions of the individual industries. Nevertheless, the modeling approach is worth mentioning in the context of multisector growth models and also contains some elements like heterogeneous dynamics of the industries that are at the heart of the evolutionary theories discussed next.

4. Evolutionary Theories

The criticism by Harberger (1998) is best addressed in a theoretical framework such as that of evolutionary economics. As becomes clear from reading Dosi (1988), Dosi and Nelson (1994) and Nelson (1995) in addition to Nelson and Winter (1982), evolutionary economics does not analyze economic processes in terms of optimal behavior and equilibrium paths. Instead, economic development is perceived as a dynamic, cumulative, open-ended process far from equilibrium paths that is subject to historical contingencies which cause the process to be path-dependent and irreversible. Economic agents are heterogeneous and face strong uncertainty (Dosi, 1988, p. 1134). This implies that they lack knowledge of all available alternatives and are unable to assign probabilities to the resulting events when making their decisions. In addition, they are endowed with only a limited capacity for information processing and therefore behave boundedly rational in the sense of Simon (1979). To generate innovations, the agents engage in search activities based on heuristic principles unless a certain aspiration level is reached (so-called satisficing behavior). Innovations are usually associated with incremental improvements of products and processes on established technological trajectories, but occasionally radical innovations appear that open up fundamentally new paradigms. Since innovations affect different industries with different intensity, economic development in evolutionary perspective is inevitably associated with structural change.

Analyses in evolutionary tradition are performed by formal as well as by appreciative theorizing. Formal theorizing means model building based on evolutionary principles. Because of heterogeneous, non-maximizing agents and the absence of equilibria, these models frequently become more complex than comparable neoclassical models. Consequently, many evolutionary models cannot be solved analytically but have to be explored through computer simulations. Besides formal theorizing, the verbal form of appreciative theorizing is well established in evolutionary economics (see Nelson and Winter, 1982, p. 46). As the following discussion of the evolutionary theories of structural change will show, the inevitable gaps that formal analyses leave open are often filled by elements of appreciative theorizing.

4.1 *Pasinetti's Model*

In two books, published in 1981 and 1993, Pasinetti presents a theory of structural change based on post-Keynesian and classical elements. In his view, structural change is an inevitable companion of long-term economic development. Pasinetti argues on what he calls a 'natural' level of investigation (Pasinetti, 1981, p. xii), which he considers to be independent of institutions of the economic system and the behavioral modes of economic agents. The 'natural' forces of structural change considered by him are population growth, learning in the process of production (i.e. through experimentation, research and the exchange of knowledge) and learning of new patterns of consumption. These driving forces of structural change lead to differential rates of change of productivity, new products and changing consumer behavior. These are interrelated through an income effect of the innovations on the structure of demand. Structural change is assumed to occur within a system of vertically integrated sectors, each of which represents the whole production process of a final consumer product and comprises all input quantities (direct and indirect via production flows within the sector) that are necessary for the production of a certain amount of the final product. The input quantities are calculated through an input–output system of horizontal relations. Pasinetti further imposes equilibrium conditions that guarantee full employment and a stable aggregate price level in the process of structural change.[17]

Learning in the production process of a sector has two basic effects. First, in the form of process innovations, learning leads to increasing labor productivity of a sector and affects the structure of relative prices. Second, in the form of product innovations, learning triggers the emergence of new sectors (see the discussion of the work of Saviotti and Pyka (2004) below for more on that). In the course of increasing real income per capita, an uneven development of consumption expenditures across sectors occurs, justified by Engel's law in combination with a hierarchy of needs in which basic needs are saturated before a desire for more recent products arises. The establishment of new patterns of consumption is imagined as a trial-and-error process that becomes effective in the long run. This process is further shaped by changes in the structure of relative prices and by the appearance of new goods.

Pasinetti ascribes only minor importance to long-term changes in relative prices. The rising real income per capita on the aggregate level due to increasing labor productivity, however, is very important in his view. Thus, the effect of process innovations on the structure of consumption is predominantly caused by their aggregate impact rather than by the sectoral divergence of productivity caused by them. Since process innovations are modeled as exogenously occurring, the dynamics within the vertically integrated sectors are exogenously determined as well and propagate through the input–output system. In effect, structural change is caused by sectorally differing developments of the growth rates of consumption which are again exogenously fixed. This is a striking parallel to Fourastié's explanation of the three-sector hypothesis, in which the sectoral growth rates of consumption are more convincingly substantiated, however.

Another striking similarity between the analyses of Fourastié and Pasinetti is that both stress that sectorally differing rates of technological progress raise real income in the aggregate which induces structural change, whereas the sectorally and time-varying income elasticities of demand shape the direction of structural change. Changes in the structure induce feedback effects on aggregate income growth. As Pasinetti (1981, p. 69) puts it: 'Increases in productivity and increases in income are two facets of the same phenomenon. Since the first implies the second, and the composition of the second determines the relevance of the first, the one cannot be considered if the other is ignored.' The influence of changes in relative prices due to differential rates of technological progress on structural change, however, are downplayed by both Fourastié and Pasinetti.

There is also a parallel to Baumol's (1967) two-sector model. Notarangelo (1999) shows that this model can be viewed as a special case of the pure-labor model analyzed in Pasinetti (1993). The modifications amount to the introduction of explicit functions for sectoral demand with differing income and price elasticities. Given a constant output ratio of the two sectors, the transition to the stagnant service sector is associated with a transition period in which the aggregate growth rate of productivity is larger than the aggregate growth rate of consumption, leading to increasing unemployment. Interestingly, in the model, service output is more rapidly expanding in nominal terms compared to the measurement in real terms, consistent with the empirical evidence reported in Baumol *et al.* (1989, chapter 6).

In sum, Pasinetti (1981, 1993) provides a rather mechanical model in which the main sources of structural change are exogenous in nature and no circular dependencies are taken into account. Only the effects of structural change on an equilibrium path are studied. The equilibrium conditions are intended to guarantee full employment and stability of the aggregate price level, but appear to be rather artificial. The analysis on the so-called 'natural' level of investigation abstracts completely from institutions and precludes the imposition of any behavioral assumptions. Pasinetti's analysis continuously switches between formal and purely verbal arguments in addition to a puzzling mixture of positive and normative elements. A last observation, although less crucial compared to the other points raised above, is that in Pasinetti's framework each sector is implicitly imagined to be populated by a single representative firm. This assumption is abandoned by the following completely different approach which relies on the replicator dynamics mechanism to model both intra-sectoral and inter-sectoral competition. With all these deficiencies, the Pasinetti model is not suitable for application to real data or, as Malinvaud (1995, p. 68) observes in his review article: '. . . in order to well grasp and hopefully master the issues raised by changing technological conditions, one cannot go very far by purely abstract reasoning; one needs to evaluate orders of magnitude and empirical evidence'.

4.2 *Replicator Dynamics*

The decisive factor influencing the direction of structural change in the models for the three-sector hypothesis as well as for Pasinetti's model is the demand side. In other evolutionary perspectives on structural change, the influence of the supply side is considered to be more important. Salter (1960) for example summarizes his empirical findings for 28 UK industries during 1924–1950 and writes that 'uneven rates of productivity growth are closely associated with the main features of inter-industry patterns of growth' (Salter, 1960, p. 124) and that 'a large part of the changes in the inter-industry structure of prices, costs, output and employment [. . .] have been associated with unequal rates of productivity increase' (Salter, 1960, p. 127). He further develops a theory in which the differential impact of technological change across industries (and thus inter-industry differences of productivity growth rates) changes relative prices and leads to differential rates of output growth.[18] These mostly verbal considerations can now be analyzed more formally using the replicator dynamics mechanism originating from population biology.

Metcalfe (1994, 1998) uses the replicator dynamics mechanism to study the development of market shares within a single industry. This mechanism postulates that the change of the market share of a firm j (out of n firms), s_j, depends on the difference of firm j's unit costs c_j and the (share-weighted) average unit costs across all n firms $\bar{c} = \Sigma_{j=1}^{n} s_j c_j$, where all s_j are bounded within the interval [0, 1] and sum to unity, $\Sigma_{j=1}^{n} s_j = 1$. Formally, in continuous time the replicator equation is stated as

$$\frac{ds_j}{dt} = \delta \cdot s_j(\bar{c} - c_j)\,\forall j = 1, \ldots, n$$

where $\delta > 0$ is a selection parameter which controls the responsiveness of the market shares to deviations of firms' unit costs from the average. Supposing constant, but differing, unit costs across firms, the dynamics are associated with increasing market shares of firms with below-average unit costs and decreasing market shares of firms with above-average unit costs. Since the average unit costs are share-weighted they will inevitably decline as a result of the share dynamics and more and more firms will be in a position of above-average unit costs and declining market shares. Eventually their market shares shrink to zero and the firms have to leave the industry.

In this context, Fisher's fundamental theorem of selection (see Metcalfe, 1994) states that the rate at which the average unit costs in an industry decline depends on the (again share-weighted) variance of the unit costs of the firms in the industry:

$$\frac{d\bar{c}}{dt} = -\delta \cdot \sum_{j=1}^{n} s_j (c_j - \bar{c})^2$$

Thus, the higher the variance of unit costs and the higher the selection parameter, the faster average unit costs decline. This leaves more and more firms with above-average unit costs and declining market shares. This, in turn, reduces the variance of unit costs so that the rate at which average unit costs decline diminishes. In the end, only the firm with the lowest unit costs survives and occupies that market with a market share of unity. Consequently, average unit costs are identical to the unit costs of this firm and the variance of unit costs equals zero.

Building on these results, Montobbio (2002) generalizes the standard replicator dynamics mechanism to construct a model of structural change at the level of industries that is explicitly driven by firm-level technological heterogeneity. In this model, structural change is the result of the interaction of demand- and supply-side factors. More precisely, structural change is shaped by selection due to differences in unit costs on the supply side, and by sorting according to industry-specific income elasticities of demand on the demand side. The degree of substitutability between the sectors is crucial for determining which of the two sides is dominating the other. This leads to aggregate productivity growth as a result of the differential productivity dynamics at the firm level, mediated by differential average productivity developments at the level of individual industries.

The economy consists of N industries that produce differentiated products and the number of industries is assumed to be constant over time. In each industry $i \in \{1, \ldots, N\}$ there are n_i firms producing a homogeneous good with different technologies which are associated with constant but differential unit costs c_{ij}, $j \in \{1, \ldots, n_i\}$, and thus different levels of productivity which are inversely related to unit costs. These unit costs are assumed to be constant over time, implying the absence of technological change at the firm level. The output level of firm j in industry i, y_{ij}, grows with the rate $d \ln y_{ij}/dt = f \cdot (p_i - c_{ij})$, where p_i is the price level in industry i and $f > 0$ is a parameter that represents the propensity to accumulate and is influenced by the specific characteristics of the financial market.[19] The selection mechanism within each industry and also across industries is assumed to work along the lines of an extended replicator equation. Using these ingredients and some simplifications, Montobbio (2002) derives the following equation (his equation (13)) for the growth rate of industry i that contains the main factors driving structural change in his model:

$$\frac{d \ln y_i}{dt} = \left(\frac{f \varphi_i + d}{f + d} \right) \frac{d \ln y}{dt} + \delta \cdot (\overline{C} - \bar{c}_i)$$

where $y = \Sigma_{i=1}^{n} y_i$ is the total output of the economy and $y_i = \sum_{j=1}^{n_i} y_{ij}$ is the output of industry i. Furthermore, $\bar{c}_i = \Sigma_{j=1}^{n_i} (s_{ij}/s_i) c_{ij}$ ($s_{ij} = y_{ij}/y$ and $s_i = y_i/y$ so that $s_{ij}/s_i = y_{ij}/y_i$, the share of firm j in industry i), $\overline{C} = \Sigma_{i=1}^{N} s_i \bar{c}_i$ and δ is shown to depend on f and the substitution parameter $d > 0$ through $fd/(f + d)$.

The parameter φ_i denotes the income elasticity of demand for the good of industry i.

The above equation shows that the growth rate of industry i depends on the growth rate of aggregate output (which is identical to aggregate income), the relative size of the industries in the economy, the income elasticity of demand, the degree of substitutability to the goods of other industries and unit cost differentials. This demonstrates the important influence of heterogeneity on structural change.

Structural change in this model is driven by two central mechanisms: sorting and selection. The first summand in the equation for the growth of industry i represents the sorting mechanism in that it determines the dependence of the output growth rate of industry i on the output growth rate of the entire economy (which is assumed to be exogenous). Equally important for sorting is the income elasticity of demand. The higher this elasticity, the more industry i benefits from aggregate growth. The second summand represents the selection mechanism. It depends on the difference between the share-weighted average costs of the entire economy and the share-weighted average costs across the firms in industry i in the fashion of the replicator dynamics mechanism. This represents the effects of competition within each industry as well as the effects of competition among the sectors that produce substitute goods. Within each industry, heterogeneous firms compete through their unit costs, leading to decreasing average unit costs $\bar{c}_i$ due to Fisher's fundamental theorem of selection reviewed above. Thus, industries interact with each other depending on the change of average unit costs within each industry compared to the other industries and furthermore depending on the degree of substitutability between each pair of industries.

Note that the growth rate of industry i is directly related to the growth rate of its share in the economy by $d \ln s_i/dt = d \ln y_i/dt - d \ln y/dt$. Thus, under the assumptions made, the output shares of the industries change depending on the relative positions of the industries with respect to the income elasticity of demand and average unit costs. In this process, sorting becomes less important as higher substitutability among the industries (higher d) increases selection pressure. Sorting becomes completely unimportant when d tends to infinity, implying that all goods are perfect substitutes.

Extending the model to the case of different degrees of substitutability across industries (heterogeneous d for each industry pair) permits the derivation of further results. According to the extended model, an industry grows at a higher rate if it is closer (in terms of substitutability) to industries with higher output growth and higher average unit costs. Importantly, structural change occurs even with constant unit costs at the firm level. Within the industries, firms are selected not only on the basis of their unit costs but also in dependence on the differential dynamics of the shares of the industries in the entire economy. Less efficient activities are inevitably driven out of the market unless the sorting process is strong enough to sustain the growth of industries with relatively higher unit costs. Sorting enhances efficiency only if it directs demand into industries with relatively lower average unit costs.

Aggregate productivity growth occurs as the result of the sorting and selection processes which induce substitution among firms and industries, despite the absence of technological change (recall that unit costs at the firm level are assumed to be constant) and a constant exogenous rate of aggregate output growth. Thus, it is the change in the sectoral composition of the economy and not technological change that drives aggregate productivity growth. This implies that in the absence of technological change the generation of variety is crucial for a positive rate of long-run productivity growth at the industry and the aggregate level. The case of uniform growth of all industries without structural change is contained in the model as a rather unrealistic special case in which all firms have the same constant unit costs and income elasticities are identical across all industries. Given that income elasticities differ, an infinite rate of substitutability across industries is another sufficient condition for uniform growth.

In a related analysis, Metcalfe *et al.* (2006) construct a model to explain the self-transformation of a multisectoral economy through structural change and differential rates of technological progress across sectors.[20] This model rests on the interaction of three distinct processes. The industry level is driven by the dynamics of productivity growth (via a technical progress function) and demand growth (via a sorting process based on differential income elasticities of demand). Both processes are linked by a constraint on aggregate dynamics that is imposed by market coordination. For each industry, a linear technical progress function is introduced which explains the growth rate of labor productivity by means of the industry's investment ratio. The investment ratio itself is explained by a linear function of the growth rate of industry output (so-called Fabricant's law after Fabricant (1942)). Industry output growth depends linearly on the price–cost margin of the industry. All productivity growth rates are simultaneously determined by the market coordination of demand and production capacity. It is demonstrated that productivity growth in each single industry depends positively on productivity growth and inversely on the income elasticities in all other industries (given that the output is a normal good).

The industry-specific productivity growth rates can be aggregated to an expression for aggregate productivity growth which depends in particular on the employment shares of the industries and the income elasticities. Despite the similarities with Montobbio (2002), the model by Metcalfe *et al.* (2006) is developed with a special focus on the explanation of aggregate productivity growth and its relation to the heterogeneous characteristics at the industry level (productivity growth rates, income elasticities, employment shares), the interaction of industries and their coordination via markets. The focus, however, is less on the explanation of changes of the employment or output shares and thus structural change. Despite that, the analysis strikingly shows that structural change is deeply involved in the 'restless' nature of capitalism (Metcalfe *et al.*, 2006, p. 8).

A major deficiency of the replicator dynamics mechanism as a model of inter-sectoral competition is the fact that replicator dynamics lead to an inevitable extinction of most industries or sectors in the limit. This immediate consequence of Fisher's fundamental theorem of selection, however, is clearly not observed in the official data since statistical agencies design the definition of industries and sectors so that these are stable for long periods of time. On the other hand, as Montobbio (2002, p. 405) points out, '[t]his 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.' The important aspect of the emergence of new industries and sectors is discussed in the following section.

A completely different approach for the investigation of the relation of productivity and structural change among the four-digit industries of the US manufacturing sector during 1958–1996 is taken in Krüger (2005, 2008). In that work the industry structure is summarized by the distribution of the value-added shares and the change of this distribution is traced over time. The dynamics of the distribution show some very interesting regularities that lead to the construction of a theoretical model based on a Markov process on a continuous state-space. In this model, the influence of differential productivity growth on structural change is combined with a demand-side explanation of the direction of structural change. The idea is that the demand for the product of an industry changes when the ratio of product quality to price of that industry changes more or less compared to the change of a benchmark. This change of demand directly translates to a change of the share of the respective industry in the total aggregate. The relation to productivity change is established by a simple dynamic model of the competition within an industry that provides a direct link between the change of the quality–price ratio relative to a benchmark and the change of the productivity gap towards the industries with the highest productivity levels. Various empirical tests are performed for checking this relation and it is found to be significantly positive across the whole support of the value-added share distribution.

4.3 *Emergence of New Sectors*

Pasinetti (1981, pp. 89ff.) already introduced the possibility of an increasing number of industries and sectors into his framework, albeit in a rather crude way. This is a very realistic aspect of structural change, although it plays no role for empirical analyses at the industry level because of the constant industrial classification of most databases. A more recent and much more elaborate analysis of qualitative change of the economic system through the emergence of new industries and sectors is presented by Saviotti and Pyka (2004). In that analysis, industries are defined quite differently from official statistics and are based on the theoretical concept of the product characteristics space, discussed in detail in Saviotti (1996). According to that concept, an industry is defined as a collection of firms producing variants of a good which are each endowed with different (but not too different) characteristics along the same dimensions of the characteristics space. Industries can thus be imagined as more or less separate clouds of points in the characteristics space, each point representing a specific product variant. The characteristics can be technical characteristics as well as service characteristics of the goods, where the former determine the latter (see Saviotti (1996, chapter 4) for examples).

Saviotti and Pyka (2004) assume that the firms in each industry produce differentiated goods and services and are engaged in search activities that lead to incremental innovations which improve product quality and productive efficiency. For each industry there exists a saturation level represented by the maximum level of possible demand. This maximum possible demand, however, need not be constant over time. Instead, it may increase if incremental innovations lead to better product quality or higher productive efficiency, the latter being associated with a lower product price. Altogether, maximum possible demand is proportional to search effort, fitness (defined as the ratio of services to price) and the volume that the sector occupies in the characteristics space.

In the model, a new industry emerges as the result of a radical innovation filling a niche in the characteristics space. Competition takes place among the firms within industries as well as between industries (intra- and inter-industrial competition). The intensity of competition within an industry depends on the density of firms in the part of the characteristics space which is occupied by that industry. This density depends on the number of firms in an industry and on how closely the characteristics of their different product variants resemble each other. Between industries, the intensity of competition depends on the pairwise distance of the industries in the characteristics space. This distance is naturally smaller if the total number of firms in the economy and the number of firms in the industries is larger.

Each industry evolves over a full life cycle with an intensity of competition that is low at first and then increases as more firms enter into the industry. When a niche in the characteristics space is filled by a radical innovation, the entrepreneur enjoys monopoly power which is subsequently eroded by the entry of other firms. Entry depends on the extent of the adjustment gap (defined as the distance of actual demand to the saturation level) and the availability of financial resources that can be invested in the sector. The increasing number of firms raises the intensity of competition and thereby reduces the incentive to enter. Conversely, the number of firms is reduced by mergers, acquisitions and more intense competition, which forces some firms to exit. Along with the rising number of firms, the production capacity of the industry increases. Since demand is assumed to be identical to output, the adjustment gap shrinks more and more. Towards the end of the life cycle of an industry, demand for the product of each sector eventually becomes saturated, inducing more firms to exit and to search for a new niche.

Important in this respect is the concept of variety, defined as ‘a measure of the extent of differentiation of the economic system’ (Saviotti and Pyka, 2004, p. 11). Variety grows as a result of the emergence of new industries and productivity growth. Productivity growth sets free resources that are required in the new industry for search activities and for the development of new products, quite analogous to the flow of events during the transition phase in Fourastié’s analysis. For variety to grow it is essential that the intensity of competition is higher within industries than between industries (Saviotti and Mani, 1995).

These considerations are introduced into a formal model which to date contains considerable simplifications of the framework just outlined. The model is particularly crude in its explanation of the important concept of the characteristics space. In the model, the level of search activities within the industry is assumed to evolve according to a logistic function, depending on cumulative demand since the emergence of the industry. By that, the level of search activities increases more rapidly early in the life cycle, when cumulative demand is low, and later on slows down when technological opportunities become increasingly exhausted. Output also follows a logistic schedule depending on the level of search activities, thereby narrowing the adjustment gap. A technical constraint is imposed which permits the emergence of a new industry only if an already existing industry reaches demand saturation with an adjustment gap of zero.

At the present stage, the model is purely deterministic but generates interesting dynamics due to its nonlinearity which are explored by simulation analyses in Saviotti and Pyka (2004). The simulation results show that economic development in the model is driven by a succession of overlapping industries, each of them following the typical life cycle pattern. Structural change and aggregate growth are interrelated, and the variety of the economic system contributes positively to economic development. Variations of parameters representing the size of technological opportunities and the learning rate show that larger technological opportunities and faster learning accelerate the process of structural change and lead to an earlier emergence of new industries. An expansive effect on industrial demand, however, can be observed only in the case of increasing technological opportunities.

The analysis of Saviotti and Pyka again highlights the technology-driven nature of structural change together with the force of intra- and inter-industry competition which makes the development of industries interdependent and endogenizes structural change. The fact that structural change at the firm and industry levels is indeed related to differential technological improvements as supposed in the models surveyed in this section will be shown in the following review of empirical studies that quantify the contribution of reallocation to aggregate productivity growth.

5. Empirical Studies of Reallocation

Another strand of literature quite different from the work discussed so far in this survey is concerned with the effects that reallocation among industries and firms exerts on aggregate productivity growth. This research originates from empirical studies of entry, exit and growth dynamics at the level of firms and individual establishments[21] (see Dunne *et al.*, 1988, 1989; Caves, 1998). The empirical studies of Baily *et al.* (1992, 1996, 2001), Disney *et al.* (2003) and Foster *et al.* (1998) all use alternative descriptive decompositions of a (share-weighted) measure of average productivity growth or productivity levels. The decompositions split productivity change into several terms, each with an illuminating economic interpretation.

The decomposition by Baily *et al.* (1996) is exemplary and is therefore described in more detail at this point. It is based on the share-weighted average productivity level $\bar{a}_t = \Sigma_{i=1}^{N} s_{it} a_{it}$, where s_{it} denotes the share of industry i (out of a total of N industries) in total employment or value added in period t and a_{it} denotes the productivity level of industry i in period t. The growth rate of average productivity between periods t and $t + 1$ can be calculated as $(\bar{a}_{t+1} - \bar{a}_t)/\bar{a}_t = \Delta\bar{a}_{t+1}/\bar{a}_t$. Baily *et al.* (1996, p. 265) decompose this growth rate according to[22]

$$\frac{\Delta\bar{a}_{t+1}}{\bar{a}_t} = \frac{\Sigma_{i=1}^{N} s_{it}\Delta a_{it+1}}{\bar{a}_t} + \frac{\Sigma_{i=1}^{N}\Delta s_{it+1}(a_{it} - \bar{a}_t)}{\bar{a}_t} + \frac{\Sigma_{i=1}^{N}\Delta s_{it+1}\Delta a_{it+1}}{\bar{a}_t}$$

The first term on the right-hand side of the formula is interpreted as the *within* effect, which is the share-weighted average productivity change of the individual industries. The second term represents the *between* effect. It is positive if industries with above-average productivity levels experience increasing shares between the periods t and $t + 1$ on average, and industries with below-average productivity levels experience decreasing shares on average. The third term is a covariance-type term which is positive if industries with increasing productivity tend to gain in terms of shares (or, more generally, if share change and productivity change tend to have the same sign). Consequently, this term is called the *covariance* effect. Together, the between effect and the covariance effect reflect the impact of structural change on aggregate productivity growth.

In the literature, different modifications and extensions of this decomposition are discussed. Baily *et al.* (1992) and Foster *et al.* (1998) propose decompositions with additional terms that represent the contributions of entering and exiting establishments to average productivity growth. These effects are irrelevant for the investigation of inter-industrial structural change because of the constant industry coverage over the whole sample period. Griliches and Regev (1995) propose an alternative decomposition that is less sensitive to measurement error but allows no clear identification of the covariance effect. Olley and Pakes (1996) decompose the share-weighted average productivity level into the sum of the equal-weighted average productivity and a term representing the effect of reallocation from below-average productivity industries to above-average productivity industries. At the industry level, Fagerberg (2000) and Peneder (2003) employ a decomposition very similar to that of Baily *et al.* (1996), although with a slightly different interpretation of the between-industry effect.

The results regarding structural change among US manufacturing establishments are succinctly surveyed by Bartelsman and Doms (2000) and Haltiwanger (2000). Although the results vary considerably across time periods, data frequency, the specification of the shares in terms of labor or output and the choice of labor productivity or total factor productivity, they can be summarized as follows. The within effect usually represents the largest contribution to aggregate productivity growth. The between effect is sometimes found to be quite small in absolute magnitude while the covariance effect is frequently positive and of considerable magnitude. Regarding entry and exit, the general pattern shows that more productive entering establishments replace less productive exiting establishments. Overall, net entry contributes positively to aggregate productivity growth. Entering establishments are usually less productive than incumbents but experience considerable productivity growth upon survival. Comparisons of different time periods show that the contribution of reallocation to average productivity growth is higher during cyclical downturns.

Disney *et al.* (2003) perform a similar productivity decomposition for UK manufacturing establishments during 1980–1992 to identify the contribution of internal restructuring (technological and organizational change among survivors) versus external restructuring (market share change, entry–exit). The findings show that external restructuring accounts for about 50% of labor productivity growth and 80%–90% of total factor productivity growth. A sizable contribution comes from entry and exit because entrants are more productive than exitors on average. Much of this effect can be attributed to multi-establishment firms closing down poorly performing plants and opening new plants which operate at high productivity. External competition appears to be an important determinant of internal restructuring and productivity growth even if sample selection is taken into account.

Cantner and Krüger (2006) investigate a sample of German manufacturing firms pertaining to 11 different industries at a roughly two-digit level of aggregation which are observed over the period 1981–1998 using decomposition formulae. In contrast to other studies, total factor productivity is measured by a nonparametric frontier function approach. The results show that structural change as well as the contributions from entering and exiting firms drive aggregate productivity dynamics to a considerable extent. These findings confirm the results of the studies for US and UK manufacturing establishments. In particular the period after the German reunification is characterized by large productivity improvements, mostly driven by structural change.

Haltiwanger (1997, 2000) emphasizes that structural change is much more intense within industries than between industries, even at the detailed four-digit level of disaggregation.[23] This may be due to the rather short time spans used in the microeconomic studies. Over longer time spans this finding may reverse. The widely evident turbulence at the level of firms and establishments also stands in contrast to the perception of structural change as a rather smooth process. There is no contradiction, however, as Schumpeter recognized long ago, when he wrote that 'the development of whole industries might still be looked at as a continuous process, a comprehensive view "ironing out" the discontinuities which occur in every single case' (Schumpeter, 1928, p. 382).

Applications of decomposition formulae to industry-level data are reported in Fagerberg (2000), Peneder (2003) and Krüger (2006a).[24] Fagerberg (2000) investigates a data set for 24 manufacturing industries in 39 countries during the period 1973–1990. He finds that for most countries the within effect dominates average labor productivity development, whereas the between effect is not very important in quantitative terms. The covariance effect appears to be negative in most countries. He concludes that on average inter-industrial structural change has not contributed much to aggregate productivity growth. Only in countries with an increasing share of the electronics industry was productivity growth noticeably higher. The magnitude of the effect exerted by the electronics industry, however, is disputed by Carree (2003). In his sample of three-digit manufacturing industries in the countries of the European Union, Peneder (2003) finds only a weak impact of structural change on average labor productivity growth. There is no systematic tendency for labor reallocation towards industries with high rates of productivity growth. The results for different industry groups are very heterogeneous and many effects cancel out in the aggregate. Krüger (2006a) applies the decomposition formula of Baily *et al.* (1996) to the four-digit industries of the US manufacturing sector and finds that structural change generally works in favor of industries with increasing productivity. The relation of differential productivity growth and structural change explains a larger part of aggregate productivity growth when total factor productivity rather than labor productivity is considered. This effect is particularly strong in the years since 1990, in high-tech industries and in durable goods producing industries.

6. Synthesis

Structural change exerts a far-reaching influence on the economic performance of nations. It takes place at various levels of aggregation, leading to a characteristic pattern of change among the three main sectors of the private economy as well as changes of the industry composition within these sectors and among firms within the individual industries. The work reviewed in this survey postulates that supply- and demand-side factors closely interact in shaping the process of structural change. On the supply side, technological progress leads either to improved production technologies or to new goods. Improved production technologies allow for producing the same goods with lower unit costs and are therefore associated with productivity improvements. New goods frequently satisfy the same needs better than the existing ones and are consequently associated with higher product quality. On the demand side, factors like relative prices, preference for higher quality (at a given price), the desire for new goods and increasing saturation in the case of the existing ones influence quantity and composition of demand for the goods of different industries. The interaction of these factors gives structural change a specific direction and also influences the speed at which this process is taking place. This leads to immediate consequences of structural change at the aggregate level which affect the growth of aggregate output, employment and productivity.

In all the theories reviewed above, technological progress drives structural change, but it is frequently the demand side that is crucial for determining which industries grow faster than others and which shrink, and it therefore shapes the direction of structural change. This is the case in the theories of Fourastié (1949/1969) and Pasinetti (1981, 1993), where technological progress raises aggregate income but structural change is determined on the demand side by Engel's laws. In other models such as that of Baumol (1967) and Durlauf (1993), it is only the technological side which shapes the process of structural change. The neoclassical multisector growth models of Echevarria (1997), Laitner (2000) and Kongsamut *et al.* (2001) aim at explaining the three-sector hypothesis by conceiving structural change as a result of the interaction of exogenous technological progress and demand schedules derived from nonhomothetic preferences.

Multisector endogenous growth models like those of Aghion and Howitt (1998, chapter 3) or Klette and Kortum (2004) are successful in explaining aggregate growth endogenously by the technological development of industries but this comes at the expense of a simplification of the demand side. A strong intertemporal technological spillover effect bounds the productivity differences among the industries and the treatment of the industries as symmetric constrains all industries to expand evenly so that no structural change takes place in these models. This is vividly criticized by Harberger (1998), who emphasizes the diversity of technological developments and growth performances across industries and sectors. More recent growth models pick up this criticism and reconcile balanced growth at the aggregate level with structural change in an endogenous growth framework, where structural change may be induced either by the supply side as in Acemoglu and Guerrieri (2006) or by the demand side as in Foellmi and Zweimüller (2002). The model of Ngai and Pissarides (2007) is able to explain a hump-shaped development of the employment share of sectors.

The simultaneous consideration of demand-side factors and technological progress is undertaken in the evolutionary models of Montobbio (2002) and Metcalfe *et al.* (2006). There, the sorting and selection processes jointly explain structural change in favor of industries with high income elasticities of demand and high rates of technological progress. Both processes also govern the development of aggregate magnitudes and in particular the aggregate rate of output growth. Whereas these models deal with structural change among a fixed number of industries, Saviotti and Pyka (2004) expand the analysis of structural change within an evolutionary framework to the emergence of new sectors. Empirical evidence in favor of the relation of structural change and differential technological progress in the form of differential rates of productivity growth is provided by various studies that perform productivity decompositions at the establishment, firm and industry level.

The synthesis of this very diverse body of research is that it is not unreasonable to expect a long-run influence of technological progress on structural change in the way that industries with relatively lower rates of productivity growth tend to shrink in terms of shares and vice versa for industries with relatively higher rates of productivity growth. This pattern also causes structural change to act as a promoter of aggregate productivity growth. Since productivity growth is naturally aggregated by a share-weighted sum of productivity changes, aggregate productivity growth may result from structural change alone, even in the absence of productivity growth at the level of individual industries. By this, an improved understanding of structural change and its interaction with differential technological developments should be at the center of all explanations of economic growth and development.

Further research, particularly on the feedback effects between structural change and aggregate growth, should therefore deserve much more attention in the future. Of value would also be a systematic exploration of the differences of structural change measured in terms of employment reallocation or in terms of value-added reallocation. The theoretical explanation of these issues almost surely requires other means of analysis than used so far. Promising candidates are agent-based computational models analyzed by simulation methods (see Tesfatsion (2006) for an overview).

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Notes

1. The specific discussion in Germany related to the 'Strukturberichterstattung', an institutionalized report of the structural development of the German economy, which is more demand-side oriented, is also omitted (see the volume edited by Gahlen (1982) and the summary of Gahlen and Rahmeyer (1982)).
2. 'It is a theory of the determination of equilibrium prices and quantities in a system of perfectly competitive markets' (Mas-Colell *et al.*, 1995, p. 511).
3. In the SIC system, thousands of specific products are defined as pertaining to a specific industry at the four-digit level. Establishments are assigned to a specific industry based on the classification of the products that dominate its overall value of shipments.
4. See Wolfe (1955) for a critical discussion of all concepts, naturally favoring his own. Wolfe (1955, p. 404) also points out that it was Fisher (1939) who coined the label of the tertiary sector for services. Fisher (1939) himself refers to its use in official statistical reports in Australia and New Zealand.
5. In contrast to Fourastié, Fisher (1952) and Clark (1957) are not as comprehensive and focus more on the role of demand-side factors.
6. Note that this page specification refers to the German edition published in 1969.
7. Fourastié (1949/1969, p. 276) himself speaks of an 'insatiable hunger for tertiary goods and services' (author's translation from the German edition). Fisher (1952, p. 832) argues that the general finding of tertiarization is robust with respect to variations in consumer tastes and the personal income distribution.
8. This prediction should not be taken too seriously. Even today the share of the primary sector is lower than the predicted 10%, and it is difficult to imagine that the secondary sector will shrink to the extent predicted by Fourastié, especially in terms of value added.
9. Not discussed here is the tendency towards an information economy which largely coincides with the tendency towards a service economy as many jobs related to information generation and processing are located in the tertiary sector (see Baumol *et al.* (1989, chapter 7) for more on that topic).
10. As usual, the time index is suppressed for a more succinct notation. Any time dependence of variables should nevertheless be clear from the context.
11. Fisher (1952, pp. 829f.) makes a similar point. In criticizing Fourastié he disputes that technological progress is absent in the tertiary sector.
12. Quibria and Harrigan (1996) criticize Gundlach's log-linear specification of the demand equation and discuss an alternative approach based on a utility function with a constant elasticity of substitution. They argue that Gundlach's results depend on the value of the elasticity of substitution. Regarding the empirical facts, the analysis of Quibria and Harrigan is not without its own problems as Gundlach (1996) points out in his reply.
13. When preferences are homothetic, the sector shares depend only on relative prices and not on the level of income (see Varian, 1992, pp. 146f.).

14. What is frequently labeled a sector in the literature could equivalently be called an industry. In this way the manufacturing sector is composed of several manufacturing industries. Nevertheless, in the course of this survey we will stick to the terminology of the literature.
15. See Howitt (2000) for an extension of the model to several countries.
16. In addition, as analyzed in Krüger (2006b), the model contains a prediction about the productivity differences across sectors that is completely at odds with the empirical facts. This deviation can be traced to the assumption of a strong intertemporal technological spillover effect that ties the productivity of the majority of industries to the leading-edge level. Evolutionary models in which those strong spillover effects are absent and which are specifically designed for the analysis of structural change are discussed later in this survey.
17. The broad framework outlined here is closer to Pasinetti's complex variant of his model of structural change, published in 1981, which takes account of the capital goods flows. In his 1993 book, Pasinetti analyses a simpler variant of the model in which labor is regarded as the single relevant production factor. There, the focus is mainly on the effects of learning on structural change.
18. Rahmeyer (1993) provides empirical evidence of the relation of productivity, prices and value added for German manufacturing industries during 1961–1985 and interprets this against the background of evolutionary theory.
19. This parameter is assumed to be constant across industries here, although Montobbio (2002) occasionally lets this parameter vary across industries.
20. In the same paper, Metcalfe *et al.* (2006) provide several pieces of empirical evidence regarding the prevalence of structural change among the four-digit industries of the US manufacturing sector during 1958–1996. A particularly interesting piece consists in the computation of the Herfindahl index for employment across the industries for each single year, which is found to be first decreasing and then increasing since the early 1980s. The absence of structural change, by contrast, would be associated with a constant Herfindahl index over time.
21. According to Haltiwanger (1997, p. 57) 'establishments are economic units at a single physical location where business is conducted or where services or industrial operations are performed. Companies are one or more establishments (e.g. General Motors) owned by the same legal entity or group of affiliated entities.' The notion of companies used by Haltiwanger is equivalent to the more common usage of firms here.
22. The proof is very easy by suitably summarizing the terms in the numerators.
23. A particularly striking fact is that during the 1970s and 1980s about 10% of all manufacturing jobs in the USA were lost in each year and about the same number were created. Out of these, only 13% are associated with reallocations between four-digit industries (see Haltiwanger, 1997, pp. 57f.). See also Davis *et al.* (1996) for related findings.
24. As an antecedent to these productivity decompositions at the industry level, Salter (1960) finds across 28 UK industries roughly at the two-digit level during 1924–1948 that the within-industry effect is about as large as the components of the labor productivity (output per head) decomposition that represent structural change. This effect of structural change is found to be considerably smaller in a comparable sample of US industries.

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