PART III

DRIVERS OF STRUCTURAL CHANGE

16

Technical Progress and Structural Change

A Long-term View

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16.1 Introduction

It is widely acknowledged that structural change, defined as the transformation of the sectoral composition of the economic system, is a salient feature of modern economic growth. Traditionally, in a long-term perspective, structural change is understood as a long-term process of re-allocation of economic activity across the three main sectors of the economy, namely agriculture, manufacturing, and services.[1] Interestingly, and notwithstanding the widespread appreciation that economic growth has been accompanied by structural change, a large part of the modern conceptualization of the process of economic growth is formulated in terms of an idealized economic system consisting of one sector (Solow 1956). This neglect may be accounted for by the implicit notion that, for many purposes, structural change is a sort of an epiphenomenon and one can study the fundamental properties of the growth process without explicitly taking into consideration the details of the changing morphology of the economic system. Still, even if this 'aggregate' perspective is predominant, it is possible to find several contributions that regard structural change and growth as intimately connected and worthy of explicit consideration.[2]

Interpretations of economic growth that highlight a prominent role for structural change point to the existence of fundamental differences across sectors in terms of technological opportunities, and relatedly of their potential for productivity growth. This 'sectoral heterogeneity' in technological opportunities provides the fundamental connection between structural change, technical progress, and aggregate economic growth, since it implies that the overall pattern of economic growth will be essentially shaped by the shifts in the sectoral composition of output. It is, however, important to recognize that patterns of structural change are also driven by factors acting on the demand side since income elasticities across products (sectors) are also heterogeneous and change over time. In this perspective, economic growth is also shaped by a reconfiguration of the patterns of demand, which in turn affect the growth and decline of the different sectors. This interplay between supply and demand factors is at the root of the historical process of structural change (Pasinetti 1983).

[1] The three-sector breakdown into agriculture (primary), manufacturing (secondary), and services (tertiary) was explicitly emphasized by Clark (1940). For a compact overview of Clark's contributions, see Maddison (2004).

[2] Structural change has received, instead, more attention by heterodox scholars, working mostly in the evolutionary and post-Keynesian traditions (see, for example, Cornwall 1977; Pasinetti 1983; Verspagen 1993; Saviotti & Pyka 2008; Montobbio 2002; Ciarli et al. 2010; Lorentz et al. 2016; Ciarli et al. 2017). Dosi et al. (2019; 2020) have recently developed a multi-country, multi-industry agent-based model which combines Schumpeterian and Kaldorian insights and displays structural ~~transformations~~ as an emergent property. Some more recent neoclassical models also pay significant attention to structural change (see, for example, Kongsamut et al. 2001; Rogerson 2008; Temple 2005; Ngai & Pissarides 2007).

Alessandro Nuvolari and Emanuele Russo, *Technical Progress and Structural Change: A Long-term Perspective View*
In: *New Perspectives on Structural Change*. Edited by: Neil Foster-McGregor, Ludovico Alcorta, Adam Szirmai, and Bart Verspagen,
Oxford University Press (2021). © Oxford University Press. DOI: 10.1093/oso/9780198850113.003.0016

A basic characterization of the process of structural change in the long run is the so-called Petty-Clark law. Clark (1940, p. 176) noted that the 'movement of working population from agriculture to manufacture, and from manufacture to commerce and services' was the 'most important concomitant of economic progress'. Clark dubbed this view 'Petty's law', pointing out that the notion had originally been adumbrated by the seventeenth-century English economist William Petty in his *Political Arithmetick* (1699). In fact, given the significance attributed in Clark's volume to the disaggregation of the economic system into agriculture, industry, and services, it is probably most appropriate to refer to the notion as the 'Petty-Clark law' (Pyatt 1984).

The main goal of this chapter is to reassess the empirical validity of broad conjectures concerning: (i) the long-run co-evolution between structural change and economic growth; and (ii) the role of manufacturing and other specific sectors as drivers of technological change and productivity growth. The chapter proceeds as follows: Section 16.2 provides a compact summary of the major contributions that have articulated conjectures concerning the nexus between long-run trends in technology and structural change; Section 16.3 contains a reconstruction of historical patterns of structural change against the background of the broad contours of technological progress since the industrial revolution; Section 16.4 considers the evidence on the role of manufacturing as 'engine of growth'; Section 16.5 discusses the evidence concerning the difference in sectoral patterns of inventive activities and elaborates the implications for the study of structural change; Section 16.6 documents recent trends in structural change in five major country groups and presents results from a productivity decomposition analysis considering differences in patterns of inventive activities; and finally Section 16.7 concludes.

16.2 Technical Progress, Structural Change, and Modern Economic Growth

A suitable starting point to discuss the literature on the connection between structural change and innovation is Simon Kuznets' appraisal of the process of modern economic growth. According to Kuznets, 'modern economic growth' represents a distinctive historical 'epoch', which is characterized by 'the extended application of science to the problems of economic production' (Kuznets 1966, p. 9).[3] Kuznets highlighted six main fundamental characteristics of the process of modern economic growth, namely:

1. High rates of growth per capita output (and of population)
2. High rates of growth of productivity (of all inputs)
3. High rates of structural transformation including shifts of employment from agriculture to industry and services
4. Changes in the structure of society and its ideology, including modernization and secularization

[3] It is important to stress that Kuznets adopted a broad conceptualization of science: 'By science we mean the study of observable and testable characteristics of the physical world in accordance with the canons of validity accepted by groups of practitioners called scientists. By science-based technology we mean applied knowledge which rests, in the reliability of its predictions and practices, upon the verified general knowledge in the sciences and upon specific observations on materials and so on' (Kuznets 1966, pp. 9–10). In perspective, Kuznets' definition resonates with Mokyr's notion of useful and reliable knowledge (Mokyr 2002).

5. Growth of global trade and international economic activities prompted by improvements in transport and communication technologies
6. Growing gaps in economic performance between advanced and backward countries.

These six characteristics can be grouped into three broad domains: characteristics 1 and 2 concern aggregate growth; characteristics 3 and 4 concerns structural change; and characteristics 5 and 6 revolve around globalization (Kuznets 1973). When Kuznets wrote, he could rely on only very limited and fragile data. Since then, substantial progress on long-run patterns of economic growth has been made.[4] Kuznets' idea was that the structural transformation was inherently related to the shifts in the 'locus of technological change' across different industrial sectors (Kuznets 1966, pp. 155–6). In Kuznets' view (Kuznets 1930), at the sectoral level, modern economic growth was driven by a sequence of 'leading sectors' undergoing a lifecycle with a first phase of rapid growth, followed by a phase of deceleration ('retardation'). This perspective on structural change is clearly in line with the perspective of Schumpeter and neo-Schumpeterian scholars such as Freeman, Louçã, and Perez (Freeman & Louçã 2001; Perez 2003).

From our perspective, the key point stressed by neo-Schumpeterian scholars is the emphasis on the critical role of discontinuities in the broad contours of technical change. These discontinuities are related to the successive deployment of a sequence of 'technological systems' or 'techno-economic paradigms'. The notion of technological system refers to constellations of major innovations characterized by strong technological and economic linkages. One can think, as a possible example, of the interdependencies and complementarities between machine-tool technology, the steam engine, and iron production during the Industrial Revolution.

According to Freeman and his associates, the gestation and deployment of each 'technological system' exerts a major impact on the rate of economic growth by means of direct backward and forward linkages, technological spillovers, and more general cost reductions of particular products. Furthermore, they argue that the sequence of these technological systems generates a pattern of growth characterized by long (Kondratiev) waves of economic development, with a duration of about fifty years for each wave as originally postulated by Schumpeter (1939). Both the periodization of economic growth in terms of Kondratiev waves and the connection between economic activity and ~~the~~ technological systems identified by Freeman and his collaborators remain, to this day, controversial (Nuvolari 2019). In particular, considering that some of the constituting elements of the technological systems identified by Freeman and his associates (such as steam power or electricity) are characterized by particularly extended cycles of development, in some cases spanning even more than a hundred years (Freeman & Louçã 2001, p. 145), it is not straightforward to interpret the deployment of these large-scale technological systems in terms of a rigid Kondratiev wave chronology. If this is the case, then at each moment of time, the productive system will be characterized by 'layers' of different technological systems that co-exist and interact. In this perspective, a simpler periodization, based on the traditional distinction between 'first', 'second', and 'third' industrial revolutions seem to

[4] See Broadberry (2016) for a reassessment of Kuznets' contribution in light of the most recent data from the Maddison project.

Table 16.1. Key characteristics of the first, second, and third industrial revolutions

	First industrial revolution	**Second industrial revolution**	**Third industrial revolution**
Approximate timing	1750–1870	1870–1969	1969–
Technological base	Mechanization	Automation	Automation/ Information processing
Power systems	Water power; steam power	Electricity	Electricity (nuclear, renewables); lithium battery
Leading sectors/Carrier branches	Cotton textiles; iron; mechanical engineering (machine tools)	Steel; chemicals; automobiles; consumer durables	Electronic components; computers; software; telecoms
Core inputs	Cotton; coal; iron	Oil; steel; plastics	Silicon
Organization of firms	Factory	Large business firms; multinationals	Large and small firms; networks
Infrastructure	Turnpikes; canals; railways	Highways; airports; telegraphy; telephone	Telecom; internet

Source: Authors'elaboration based on Lee & Rhode (2018)

provide a better characterization of the process of economic growth than the Kondratiev chronology (von Tunzelmann 1995, pp. 97–100; Nuvolari 2019).[5]

Table 16.1 provides a stylized overview of the characteristics of the three industrial revolutions. The table provides a vivid illustration of the potential connection between technology and structural change. Each industrial revolution both resulted in a re-articulation of existing productive systems (think about the reconfiguration of factory layout prompted by the adoption of electric power) and in the emergence of new products and industries (coupled with the disappearance of some old products).

The constellation of innovations of each industrial revolution prompts trajectories of improvement that are mutually interacting, possibly reinforcing each other in a 'autocatalytic' fashion. This means that innovations in one sector are, simultaneously, dependent on innovations from other domains, but also capable of inducing further advances in related sectors. This perspective concerning the emergence of 'autocatalytic' connection between technological trajectories at the sectoral level is reminiscent of the notion of 'development blocks' introduced by the Swedish economist, Erik Dahmen (Carlsson & Henriksson 1991) and of 'leading sectors' put forward by Rostow (1960, 1990).

16.3 Structural Change and Modernization

Kuznets and Clark regarded the shift of employment from agriculture to manufacturing, and subsequently to services, as one of the salient features of modern economic growth. Recent research suggests that the shift was more gradual than Kuznets' notion of 'high rates of structural transformation' suggests. Furthermore, in countries such as England and the

[5] For a contribution highlighting the connection between structural change and the three industrial revolutions in the United States case, see Lee & Rhode (2018).

Netherlands the shift had already begun in the early modern period, preceding the Industrial Revolution. Figure 16.1 shows some recent estimates for England suggesting that a significant decline of agriculture had already taken place in the period 1500–1700.

Data for the period before 1800 are available only for a very limited number of countries. ~~For the period after~~ 1800, data on the sectoral composition of employment and output are available and they allow for an investigation of long-run patterns of structural change.

Figure 16.2 shows the evolution of sectoral employment shares at different per capita income levels for the 'aggregate' across different country groups.[6] In Figure 16.3 we plot sectoral shares of output (value added) and employment against real GDP per capita for eighteen (mostly advanced) countries.[7] Data points are divided into three periods corresponding

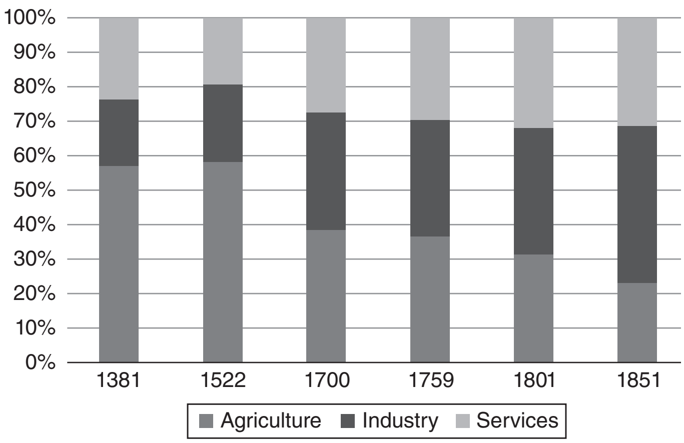

Figure 16.1. Share of labour force by sector in England (1381–1700) and Great Britain (1700–1851)

Source: Broadberry et al. (2015).

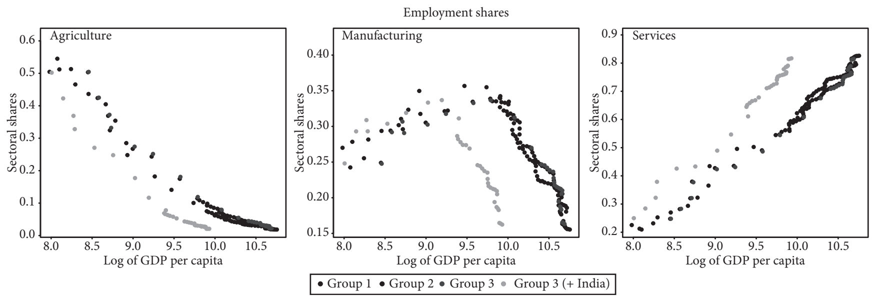

Figure 16.2. Sectoral employment shares versus income per capita aggregated across different country groups

Source: Authors' elaboration

[6] The following groups are considered. Group 1: Belgium, Denmark, Spain, France, Great Britain, Sweden, and the United States; Group 2: Group 1 plus Finland, Italy, Japan, and the Netherlands; Group 3: Group 2 + Australia, Canada, and Denmark.

[7] The same exercise is presented in Herrendorf et al. (2014). Here we extend their analysis by considering a broader set of countries and a larger time span. Details on the construction of the historical dataset are given in Appendix A of the working paper version of this chapter (Nuvolari & Russo 2019).

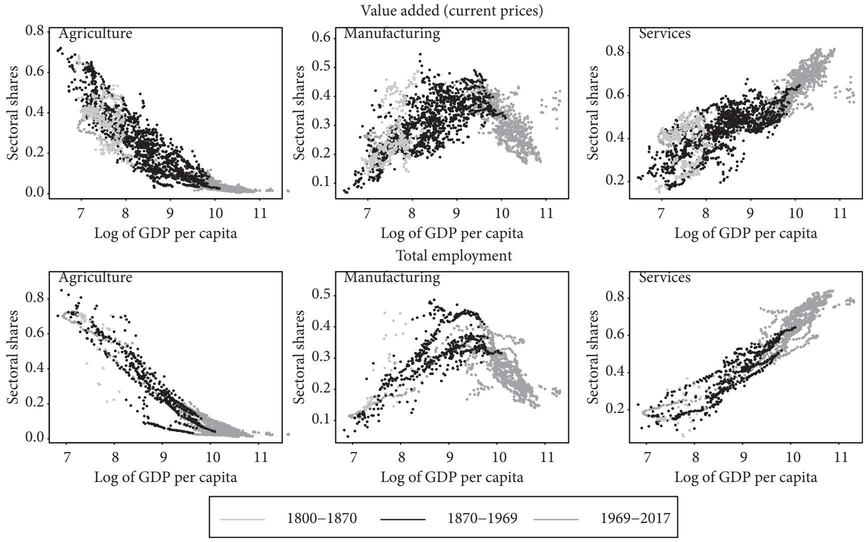

Figure 16.3. Sectoral shares versus GDP per capita, grouped by industrial revolution periods (all countries for which data are available before 1950)
Source: Authors' elaboration

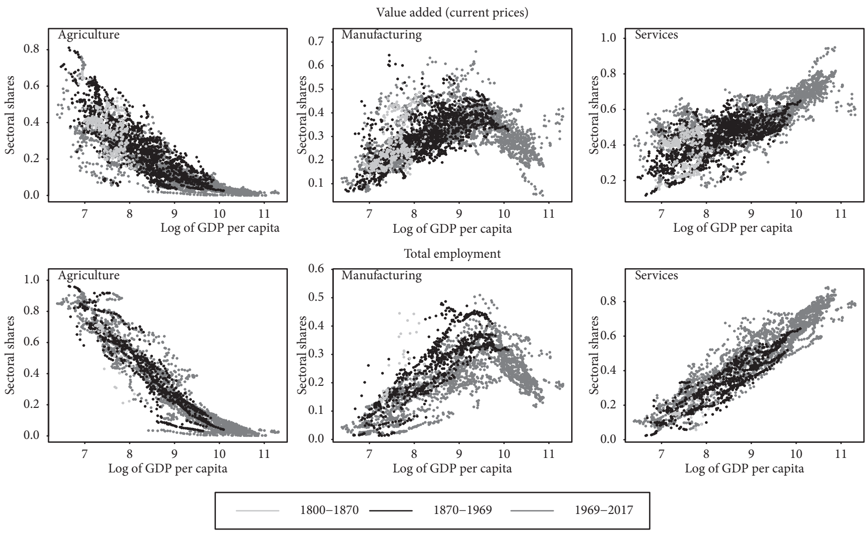

Figure 16.4. Sectoral shares versus GDP per capita, grouped by industrial revolution periods (including less developed countries with observations after 1950)
Source: Authors' elaboration

to major industrial revolutions. Figure 16.4 includes in the same plot observations for less developed countries which are available from 1950 only. Table 16.2 shows the predicted values of sectoral shares and other outcomes of the modernization process such as education, life-expectancy, and urbanization at different levels of GDP per capita. The model used for predictions is the following polynomial regression:

$$DepVar_{it} = \beta_0 + \beta_1 \log y_{it} + \beta_2 (\log y_{it})^2 + \beta_3 \log Pop_{it} + \beta_4 (\log Pop_{it})^2 + \sum_{i=1}^{N} D_i + \varepsilon_{it} \quad (1)$$

where y is real GDP per capita, *Pop* is population and *D* represents the country fixed effect. As dependent variables we use respectively the sectoral shares of agriculture, manufacturing, and services, the average years of schooling (*SCHOOL*), life expectancy (*LIFEXP*), and the urbanization rate (*URBANIZATION*). The simulated dynamics of the model assuming a representative country with median population is reported for each variable in Figure 16.5.[8] The main finding emerging from Figure 16.4 and Table 16.2 is that the Petty-Clark law of the movement from agriculture to manufacturing and to services is a broadly accurate conjecture. There seems a broad correspondence also between patterns of structural change and the periodization of the three industrial revolutions we have outlined in Table 16.1. Nevertheless, such a correspondence turns out to apply exclusively to first industrializers whereas structural transformation for less developed countries appears to be more disconnected from the unfolding of the three industrial revolutions (see Figure 16.5).

16.4 Manufacturing as an Engine of Growth?

The analysis in the previous section suggests that industrialization (understood as the shift of labour from agriculture to manufacturing) is a necessary condition for triggering economic development. With the exceptions of a few resource-rich countries and small open economies, no country has managed to take off without expanding its manufacturing sector (Szirmai 2012). Drawing on this type of evidence, some authors have postulated the general role of manufacturing as an engine of growth operating at all development levels (Kaldor 1967; Cornwall 1977).[9] This hypothesis is grounded on a set of compelling empirical and theoretical arguments and has, therefore, exerted a strong influence on development economists over the last decades. From a historical point of view, evidence largely suggests that most technological innovations originate within the manufacturing sector (Landes 1969; Rosenberg 1982; Freeman & Louçã 2001), while services are characterized by relatively low rates of technical change (Baumol 1967).[10] Manufacturing also exhibits scope for dynamic and static economies of scale, significantly larger than in traditional (or agricultural) and service activities as well as broad opportunities for the adoption of capital-embodied technologies (Young 1928; Myrdal 1957; Kaldor 1967; Cornwall 1977). Forward and backward linkages across firms and sub-industries are stronger in the industrial sector implying fast propagation of demand and technological shocks via demand linkages and knowledge spillovers (Hirschman 1958). Moreover, it has been recently put forward that technological spillovers in manufacturing are also large across national borders offering opportunities for unconditional convergence of laggard economies (Rodrik 2012, 2016a). Finally, especially at early stages of development, there are margins for exploiting the increasing demand of manufactured goods stemming from rising income levels (i.e. Engel's law).

[8] In the working paper version, we report the model estimates used for simulations (see Appendix B).

[9] An extended survey of the arguments and the literature on the manufacturing as an 'engine of growth' hypothesis is found in Szirmai (2012).

[10] The classical view of services as involving less-dynamic activities has been recently questioned considering the emergence and diffusion of ICT technologies. For a rehabilitation of agriculture and of 'biological innovation', see Olmstead & Rhode (2008). A detailed discussion is provided in the Section 16.5.

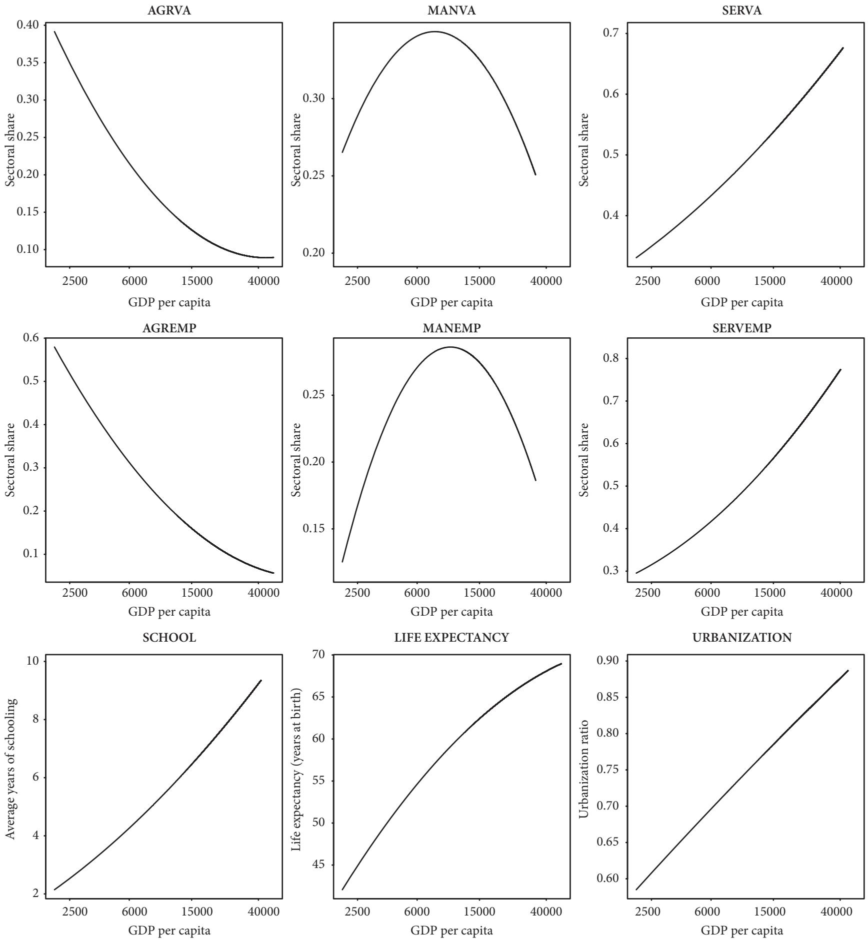

Figure 16.5. Simulated dynamics of sectoral shares and modernization variables (assuming median population size and removing fixed effects)
Source: Authors' elaboration

The 'engine of growth' hypothesis can be tested in different samples using a variety of empirical techniques. The selection of countries included in the analysis matters greatly since advanced nations, as already discussed, are nowadays dominated by the service sector and display a distinct behaviour with respect to laggards. In terms of statistical approaches, we may distinguish between studies relying on descriptive evidence, econometric exercises, or growth accounting methods. From a purely descriptive perspective, Szirmai (2012) contrasts the levels and growth rates of productivity in manufacturing vis-à-vis other sectors in a sample of developing and developed countries (excluding African economies). While productivity levels generally tend to be higher in manufacturing (see also McMillan et al. 2014), faster growth is often observed from the 1980s onwards in agriculture, especially in developed countries.[11] In other terms, shifting resources from traditional activities to industrial ones provides a static 'structural change bonus' but generally not dynamic gains.

[11] Szirmai (2012) interprets such results as originating from the so-called industrialization of agriculture, i.e. rising capital intensities and declining shares of value added in the sector.

A second stream of literature introduces sectoral shares in growth regressions where the dependent variable is a proxy of aggregate productivity growth. In comparison to growth accounting techniques, this approach has the advantage of estimating the net contribution of changing sectoral shares, including external effects and spillovers, but is affected by the well-known econometric shortcomings of growth regressions.[12] Early studies along these lines suggested a strong and positive effect of manufacturing on growth, in particular during phases of technological catching up, which nevertheless exhibits a declining pattern in recent times, probably due to the emergence of ICT-intensive service activities (Fagerberg & Verspagen 1999, 2002). More recently, Szirmai & Verspagen (2015) investigate the same relationships in a larger sample of ninety-two countries including many developing ones. The findings point to a generally modest effect of manufacturing shares on growth when time observations are pooled. However, when considering different sub-periods, a positive impact is found only for 1970–1990, while, interestingly, positive and negative interaction effects with human capital and income gaps are also found. This, in turn, hints at a strong growth-promoting role of manufacturing in laggard countries with a well-educated labour force. Rodrik (2009) presents regressions for five-year intervals in a panel dataset controlling for trade shares as well as country and time fixed effects. His estimates are consistent with the general conclusion from the literature according to which rising manufacturing shares matter for growth, especially in less developed areas of the world. The analysis by Su & Yao (2017) focuses on middle-income countries and uses three different econometric approaches—Granger causality tests, cross-sectional regressions, and panel regressions—concluding that manufacturing expansions trigger the growth of service activities and, thus, manufacturing still acts as the key engine of development. In tune with these findings, Marconi et al. (2016) exploit a dynamic panel, including countries at all stages of development, to test the two fundamental Kaldorian laws relating manufacturing to income and productivity growth (Kaldor 1966). They confirm that both of Kaldor's laws are supported by the data and that manufacturing exports, in particular, are capable of spurring GDP and productivity increases.

Taking their cue from the recent interest on the determinants of medium-run fluctuations (Pritchett 2000; Hausmann et al. 2006), some studies examine the effect of structural change on specific growth episodes. Szirmai & Foster-McGregor (2017) include manufacturing shares as explanatory variables for the duration of positive episodes and the probability of their end. High manufacturing shares, together with a diversified structure of production, turn out to be associated with a longer duration of growth phases and, thus, they affect countries' ability to sustain growth over the long run.[13] A different perspective is found in Timmer & de Vries (2009) who use productivity decomposition methods to measure the contribution of various sectors during acceleration episodes. They find that, notwithstanding the general positive effect of manufacturing, the largest part of growth during accelerations is explained by productivity gains within market services. In the same fashion, other studies highlight the dominant role of non-traditional service activities over manufacturing ones (Dasgupta & Singh 2005, 2006; Ghani & O'Connell 2014). For instance, it has been pointed out that to a large degree the disappointing European growth performance during the last two decades, in comparison to the United States, may be the result of the slow accumulation of ICT capital in market services (Inklaar et al. 2005;

[12] For in-depth critiques of growth regressions, see, for example, Durlauf et al. (2005) and Pritchett (2000).
[13] Aizenman & Spiegel (2010) make a similar point on the impact of diversified production structure on growth take-offs.

Timmer & van Ark 2005; Inklaar et al. 2008; van Ark et al. 2008). To account for this evidence, Lavopa & Szirmai (2018, Chapter 11, this volume) propose shifting the emphasis from manufacturing to the broader modern sector, defined to include industry and tradable services (e.g. telecommunication, transport).

Another source of scepticism comes from the evidence on 'premature deindustrialization', with several developing countries experiencing declines in manufacturing shares at much lower levels of income per capita (Dasgupta & Singh 2006; Ghani & O'Connell 2014; Rodrik 2016b; Tregenna et al. Chapter 17, this volume). These contributions tend to stress the shrinking opportunities for manufacturing-led growth and, in consequence, the need for poor countries to reconsider their development strategies, placing more emphasis on other modern activities. Nevertheless, this argument has been questioned considering new evidence presented by Haraguchi et al. (2017). This study shows that the premature drops in manufacturing shares are not due to changing structural characteristics of the sector but are instead related to the increasing concentration of industrial activities in a small group of fast-growing economies. According to the authors, the prescription for backward nations is to emulate the path followed by today's emerging countries and to exploit future opportunities arising from their next deindustrialization phase.

To summarize, although industrialization probably still represents a necessary stage of development for low- and middle-income economies, the evidence concerning the 'strong' form of the hypothesis of manufacturing as the engine of growth is mixed. Focusing on rich nations, manufacturing appears to have lost part of its dynamism as compared to ICT-intensive service sectors and to modern agriculture. Of course, this may well be the result of innovations originating in the industrial sector (e.g. semiconductors) which then spread to other activities, making further innovations possible (e.g. new software). This result tends to suggest the need for going beyond the conventional contrast between manufacturing and other traditional activities. To account for such new findings, in Section 16.5 we move to an analysis of sector-specific patterns of innovation and technical change at finer levels of aggregation.

16.5 Sectoral Patterns of Innovation and Structural Change

As noted by Kuznets, the traditional emphasis on structural change looking at agriculture, industry, and services is not able to capture in detail the connection between structural transformation and technical change. On this issue, Kuznets noted:

> Since the high and accelerated rate of technical change is a major source of the high rates of growth of per capita product and productivity in modern times and is also responsible for striking shifts in production structure, it is frustrating that the available sectoral classifications fail to separate new industries from old, and distinguish those affected by technological innovations. (Kuznets 1971, p. 315; cited in Rostow 1990, p. 355)

Along somewhat similar lines, several scholars in the field of innovation studies have emphasized the substantial heterogeneity characterizing the features of the innovative process in different sectors (Nelson & Winter 1977; Dosi 1982; Freeman et al. 1982; Perez 2003; Pavitt 1984) by trying to design characterizations of sectoral patterns of innovation that could be also useful for the study of long-run structural transformation.

A first key aspect concerns the extent to which specific industries can reap the benefits stemming from new techno-economic paradigms. As stated before, the emergence of radical innovations exhibiting high degrees of pervasiveness and complementarity opens up new sets of technological opportunities, which are exploited differently depending on sector-specific characteristics. Most importantly, emerging activities as well as industries showing a strong relatedness in terms of knowledge base and capabilities (with respect to the cluster of new technologies) are more likely to follow dynamic trajectories, providing a great contribution to aggregate productivity growth (Kuznets 1930; Burns 1934; Schumpeter 1939).

Motivated by such a great deal of sectoral heterogeneity, a large literature on sectoral patterns of innovation has emerged in recent years. On the one hand, some case studies provide detailed accounts of performance and trajectories of isolated industries (Dosi 1984; Bresnahan & Malerba 1999; Mazzucato & Dosi 2006; Malerba & Orsenigo 2015).[14] On the other hand, from a comparative perspective, some studies focus on the identification of cross-sectoral and cross-country differences across various domains (e.g. technology, institutions).

As far as this strand of research is concerned, a useful starting point is the notion of a sectoral innovation system (SIS) which is defined as ‘the set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production, and sale of those products’ (Malerba 2002, p. 250). A SIS is composed of the relevant players operating in the sector (e.g. firms, organizations, individuals), the structure of network interactions among agents, the knowledge base, the institutional framework in which agents’ behaviour is ‘embedded’, and demand conditions. The characteristics of a specific SIS have been postulated to shape the technological trajectories of the industry and ultimately its growth rates over time (Breschi & Malerba 1997; Malerba 2002; Malerba & Mani 2009). More precisely, the interactions among different elements of a SIS define the sector-specific technological regime (TR) which is seen as the dominant driver of industry evolution. The concept of TR was originally introduced by evolutionary economists (Nelson & Winter 1982; Winter 1984) to describe the environment in which firms’ innovative activities take place along some key dimensions (e.g. cumulativeness and appropriability conditions, technological opportunities).[15] A popular distinction in the literature is between the so-called Schumpeter Mark I and Schumpeter Mark II (Malerba & Orsenigo 1995). The former regime is characterized by relatively low entry costs and innovations are primarily carried out by new firms which, if successful, typically replace incumbents. On the contrary, in Schumpeter Mark II industries, barriers to entry provide a cumulative innovative advantage for existing firms. Several works attempt to identify different TR and to make a link with sectoral performances (Breschi & Malerba 1997; Breschi et al. 2000; Marsili & Verspagen 2002; Malerba & Orsenigo 2015; Park & Lee 2006). While early contributions tested the role of isolated variables (e.g. R&D intensities and spillovers) in explaining industry productivity growth, more recently the emphasis has shifted towards multi-dimensional models including some elements defining SIS and TRs.[16] In particular, Castellacci (2007) suggests that the links between TRs and productivity

[14] From a theoretical point of view, history-friendly models have been developed to replicate the observed historical records of a given sector (Malerba et al. 1999; Malerba & Orsenigo 2002).

[15] Notice that one should not identify the TR exclusively with the technological intensity of the sector. Industries with similar technological contents may follow radically alternative trajectories as a result of the differences in the structure of their SIS and TR. An illustrative example of such phenomena is provided by Mani (2009) which analyses the case of pharmaceuticals and telecommunication equipment in India.

[16] These analyses are typically carried out for a cross-section of industries from different countries. For a survey focused on the impact of R&D variables on productivity see Los & Verspagen (2004), while a comprehensive discussion of the literature is found in Castellacci (2007).

Table 16.2. Variable forecasts as a function of different income levels

Dependent variable	Forecast values at:				
	$2,000	**$5,000**	**$15,000**	**$30,000**	**$50,000**
AGRVA	0.40	0.25	0.14	0.11	0.11
MANVA	0.24	0.31	0.30	0.24	0.17
SERVA	0.34	0.43	0.55	0.64	0.72
AGREMP	0.56	0.34	0.15	0.07	0.03
MANEMP	0.15	0.26	0.27	0.20	0.12
SERVEMP	0.29	0.40	0.58	0.73	0.85
SCHOOL	2.14	3.87	6.46	8.37	9.92
LIFEXP	43.55	52.26	52.44	66.67	69.03
URBANIZATION	0.58	0.68	0.79	0.85	0.90

Notes: AGRVA, MANVA, and SERVA refer to shares of agriculture, manufacturing, and services in value added respectively, while AGREMP, MANEMP, and SERVEMP refer to the shares of these three sectors in employment respectively. Income per capita is expressed in 2011 US$ (multiple price benchmarks). Forecast values refer to a representative country with median population size and controlling for country fixed effects.

Source: Authors' elaboration.

growth change across sectors depending on whether they display Schumpeter Mark I or Schumpeter Mark II patterns. Fontana et al. (2012) corroborate such a distinction by showing that breakthrough inventions tend to take place mostly in industries characterized by Schumpeter Mark I environments.

More generally, results from the literature on TRs and sectoral performance suggest positive direct and indirect effects associated with technological (e.g. R&D, patents, and technological opportunities) and educational (e.g. skills and human capital) variables, while appropriability conditions and market size seem to operate in the opposite direction (Castellacci 2007).

Another related approach, pioneered by Pavitt (1984), aims to provide taxonomies of sectoral technological patterns based on firms' innovation sources, strategies, and user-producer relationships. Rather than focusing on technological and institutional regimes, here the emphasis is on the process of creation and diffusion of new ideas and products. A crucial aspect, therefore, concerns the input–output relationships that exist across innovative firms operating in different sectors, on the linkages with general scientific advances, and on the ability to generate innovations internally. The original Pavitt taxonomy identifies four dominant classes: (i) science-based industries characterized by large firms relying on internal R&D and evolving in close connection with advances in scientific knowledge; (ii) specialized supplier industries populated mainly by small or medium-sized producers of machinery and tools embedding process innovations as well as forms of tacit knowledge; (iii) supplier-dominated industries producing final goods which typically adopt technologies developed elsewhere in the economy; and (iv) scale-intensive industries associated with the Fordist era of mass production where scale economies are prominent and R&D is performed in-house or in cooperation with specialized suppliers.[17] It has been conjectured that the emergence of each sectoral class can be linked to different historical

[17] This taxonomy has been used as a guideline for several micro and meso empirical investigations, with examples including Dosi et al. (1990), Padoan (1998), Dosi et al. (2008), and Bogliacino & Pianta (2010). For an early survey of the literature see Archibugi (2001).

Table 16.3. Pavitt taxonomy and the three industrial revolutions

Phase of development	Typical industries	Pavitt's category
First industrial revolution (1st phase)	Textiles; pottery	Supplier dominated
First industrial revolution (2nd phase)	Mechanical engineering; machine tools	Specialised suppliers
Second industrial revolution (1st phase)	Chemicals; electrical machinery	Science based
Second industrial revolution (2nd phase)	Automobiles; consumer durables; plastics	Scale intensive
Third industrial revolution (1st phase)	Microelectronics; computers; software; internet	Information intensive

Source: Authors' elaboration based on Archibugi (2001).

phases of capitalist development (Archibugi 2001). Table 16.3 reports the typical sectors in each category and the associated phase of development.

The availability of data from Community Innovation Surveys (CIS) has made further refinements of the original Pavitt taxonomy possible (Evangelista et al. 1997; Evangelista 1999; Mairesse & Mohnen 2002; Bogliacino & Pianta 2016). However, early classifications tend to be uniquely concerned with manufacturing activities. As discussed in the previous section, such a choice has its origin in Baumol's traditional view of manufacturing as the dominant locus of technological innovation and of services as productivity-stagnant activities (Baumol 1967). Clearly, radical discoveries in the area of information and communication technologies (ICTs) have called into question such a perspective, with major advances along the new paradigm allowing for productivity increases in existing services (e.g. finance, engineering) and revealing the great potential for dynamism of brand new activities (e.g. software, consultancy, mobile networks). The rise of the latter has been favoured by major organizational changes of the post-Fordist era whereas a continuous outsourcing process has led to the disintegration of traditional manufacturing companies into complex network-based entities in which activities formerly conducted internally are now provided by specialized service suppliers. Gallouj & Savona (2009) show that measurement errors and definition problems have largely affected the conventional view on service innovation. Considering the specificities of service innovation activities leads to a new perspective which acknowledges the scope for sustained productivity gains even in the service part of the economy. Motivated by these insights—and by the dominant role exerted by services in advanced economies—a body of literature has emerged proposing new taxonomies of innovation modes in services (Gallouj & Weinstein 1997; Evangelista 2000; Miozzo & Soete 2001; Evangelista & Savona 2003; Drejer 2004; Camacho & Rodriguez 2008). Pavitt himself, in a later joint contribution (Tidd et al. 2005), extended his own classification to incorporate the broad category of *information intensive* service industries (e.g. finance, telecommunications, consultancy).

A more comprehensive taxonomy provided by Castellacci (2008) avoids the fragmentation between manufacturing and services and includes a more detailed classification of service industries. The scheme adopted has two main dimensions: the role assumed by each industry as a supplier or user of innovations, i.e. its position in the input–output network of the economy; and the level of technological sophistication which includes a broad definition of technical capabilities together with the ability to generate innovations internally. The resulting taxonomy includes four major classes, each composed of two sub-categories:

- Advanced knowledge providers: Firms populating these industries are typically small or medium-sized suppliers of technological knowledge for other sectors and master sophisticated technical competences. Innovation is carried out internally and in cooperation with clients. Within this category we find Pavitt's specialized suppliers (e.g. machine-producing sectors) and knowledge-intensive business services (e.g. R&D, consultancy).
- Infrastructural services: industries concerned with the production of intermediate products and services which play the role of supportive infrastructures for companies engaged in other activities. The average firm size tends to be large and the level of technological sophistication is not particularly high as they rely on the provision of machinery and knowledge from external suppliers. Here we can distinguish between physical infrastructures (e.g. transport and wholesale trade) and network infrastructures (e.g. telecommunications and finance).
- Mass production goods: the core of the Fordist system of production that includes scale-intensive (e.g. motor vehicles) and science-based (e.g. pharmaceuticals, electronics) industries. Both are close to the final part of the supply chain and are characterized by substantial technological capabilities. While the former tends to rely on both in-house R&D and, especially nowadays, on external collaborations with advanced knowledge providers, the latter of which are more dependent on scientific discoveries achieved by research institutions.
- Personal goods and services: sectors populated by (generally small-sized) enterprises which provide goods and services to final users and are characterized by a low technological content, being heavily dependent on external knowledge generated by their suppliers. Innovations in these areas mostly take the form of slow incremental improvements in the production process and in product quality. Under this label fall supplier-dominated goods (e.g. food and textiles) and services (e.g. retail trade, hotels and restaurants).

The vast cross-sectoral heterogeneity documented here clearly heeds the general conjecture, put forward in previous sections, according to which structural transformations entail a large potential for productivity growth via differential rates of technical progress across industries. Growth-promoting activities located at the bottom of the innovation supply chain do not belong exclusively to the industrial sector but also include a bunch of hi-tech market services (e.g. technical consultancy, R&D, telecommunications).

On the grounds of such evidence, the following section aims to provide an overview of the structural trajectories followed by countries at different development levels in the post-WWII period.

16.6 Structural Change Patterns and Productivity Growth

To assess empirically the precise connection between structural change and aggregate productivity growth one needs sectoral data on factor use and output at sufficiently low aggregation levels. Data of this kind are available from the post-WWII period for a large sample of countries. Of course, data quality and coverage vary significantly between developed and developing countries. For the former, researchers involved in the KLEMS project (O'Mahony & Timmer 2009) have constructed a database including figures for value added and five types of input variables in thirty-four industries, from 1970 onwards. Data for developing countries are typically limited to ten major sectors and are more likely to be affected by measurement errors due to the large presence of the informal sector (Timmer & de Vries 2009). Based on these datasets, several empirical papers have investigated structural change patterns in different groups of countries and the potential impact on aggregate income and productivity growth. These studies shed a light on successful development cases and best practices as well as parallel failures and missing opportunities providing, in this way, relevant prescriptions for national policymakers. In this section we first provide an overview of the key findings from this literature for five major country groups. We then present new evidence linking productivity decomposition methods to the literature on sectoral innovation patterns.

16.6.1 The Evidence from Five Major Country Groups

16.6.1.1 The United States and Western Europe

As widely documented, Western Europe experienced a phase of rapid catching up with respect to the United States after WWII. This period was characterized by massive imitation of foreign technologies supported by institutions of the Fordist type and by a relatively well-educated labour force (Crafts & Toniolo 1996). Structural change during this period contributed positively to overall productivity growth by shifting resources mainly towards sectors producing mass production goods (Crafts & Toniolo 1996; van Ark et al. 2008). In a growth accounting framework, Temple (2001) computes re-allocation effects during the European boom ranging from a tenth to a seventh of total productivity growth with stronger effects for countries such as Italy and Germany. After 1970, both Western Europe and the United States experienced a substantial growth slowdown followed by divergent dynamics from the 1990s onwards. Indeed, during the last two decades Europe entered a phase of relative stagnation while productivity in the US economy accelerated. A series of studies document this pattern and attempt to pin down the potential driving forces (Inklaar et al. 2005; Timmer & van Ark 2005; Inklaar et al. 2008; van Ark et al. 2008; Jorgenson & Timmer 2011). Among them, differential sectoral trajectories have been shown to be relatively important. First, Jorgenson & Timmer (2011) report an increasing relative importance of ICT-producing industries and market services in the United States which now display higher productivity than traditional manufacturing activities (both in levels and in growth rates).[18] In both areas Europe is lagging behind, with lower investment rates and a slower evolution of productivity. Productivity decompositions reveal that much of the divergent dynamics can be accounted for by improvements within these ICT-intensive activities rather than through re-allocation effects (Jorgenson & Timmer 2011).

16.6.1.2 East Asia and Japan

East Asian countries stand out as exceptional cases for their rapid development during the last fifty to sixty years. Japan was the first country to join the club of catching up European

[18] Within market services there is considerable heterogeneity. While distribution activities display fast growth rates, financial and personal services are characterized by a more sluggish dynamic.

economies in the 1950s, followed a decade later by the Republic of Korea, Taiwan POC, Singapore, and Hong Kong.[19]

How does such exceptional performance relate to structural transformations? Although there is an open debate an increasing consensus seems to interpret the Asian miracle, in line with a technology-gap perspective (Abramovitz 1986; Gerschenkron 1962), as the result of radical changes in economic structure aimed at developing competitive advantages in technologically dynamic sectors (Amsden 1989; Nelson & Pack 1999).[20] This process entailed learning efforts in the private sector to develop adequate production and organizational capabilities, educational achievements in the creation of managerial and scientific skills, and a coordinating role played by the state in the form of export-oriented industrial policies (Amsden 1989; Wade 1990; Kim 1993; Nelson & Pack 1999; Kim & Nelson 2000). As in other instances, the contribution of structural change can be measured using accounting techniques. A series of studies finds a strong positive effect of structural change (around 30 per cent of total productivity growth) in the early phases of Asian development and an increasing role of within-sector productivity growth in later stages, as the scope for mobilizing resources towards modern activities reduced (McMillan et al. 2014; Timmer et al. 2015; Foster-McGregor & Verspagen 2016). Notwithstanding the decreasing contribution of structural change, van Ark & Timmer (2003) document substantial productivity gains as a result of within-manufacturing shifts from labour-intensive to ICT-intensive industries during the transition from middle- to high-income levels.[21] Interestingly, Asian countries did not experience a negative impact of sectoral re-allocations in dynamic terms, a pattern which is instead observed in Africa and Latin America (Timmer et al. 2015; Foster-McGregor & Verspagen 2016). Timmer et al. (2015) show that this stems from the ability to achieve sustained growth rates in market services—in particular in trade and distribution activities—which have steadily increased their importance in all regions over the last two decades.

Timmer et al. (2015) also offers insights into the Japanese slowdown observed from the 1990s onwards in comparison to other Asian experiences, with the largest gap to fast-growing neighbours appearing to be in the within component. The contribution of structural change terms, meanwhile, are in line with the regional average.

16.6.1.3 Latin America

Among less developed nations, Latin America was the most industrialized region in the 1950s (Szirmai 2012; Timmer et al. 2015). Nevertheless, countries in this region never managed to embark on a process of self-sustained industrialization. This resulted in systematic failures to catch up with leader nations as well as in turbulent growth paths characterized by acceleration episodes and subsequent crises (Hausmann et al. 2005; Pritchett 2000; Russo et al. 2019). Among the explanations put forward for this failure, economists tend to stress factors such as bad institutions, a lack of investment in physical and human capital, as well as the perverse interaction between natural resource

[19] For the sake of clarity, we refer here to the experiences of Japan and the four major Asian Tigers. To a moderate extent, the evidence discussed may be generalized also to a second wave of Asian industrializers (e.g. Malaysia, Indonesia).

[20] Alternative explanations tend to emphasize inputs and capital accumulation rather than improvements in total factor productivity (e.g. Young 1992; Krugman 1994). A critical discussion of this interpretation is provided by Felipe (1999).

[21] This evidence is in contrast to other studies stressing the prevalence of manufacturing-wide effects over within-manufacturing re-allocations (Timmer & Szirmai 2000; Fagerberg 2000).

endowments and specialization trajectories towards labour- and resource-intensive goods (e.g. Solimano & Soto 2006; Restuccia 2013; ECLAC 2017). This last aspect is particularly important for the structuralist tradition (Prebisch 1950; Cimoli & Katz 2003; Cimoli & Correa 2005; Cimoli & Porcile 2013; Porcile Chapter 3, this volume) that identifies policy failures in triggering upgrades of the productive structures as the biggest bottleneck to development. Hence, according to this interpretation, structural change lies at the centre of Latin American problems. Indeed, several countries since the 1970s have experienced 'premature deindustrialization', i.e. a fall in manufacturing shares at relatively low income levels (Rodrik 2016b). Consequently, the short-lived periods of accelerations have been mainly driven by temporary productivity spurts in market services rather than in manufacturing (Timmer & de Vries 2009). A recent contribution by Timmer et al. (2015) also shows that during the period 1960–1975 Latin American economies were experiencing growth-enhancing structural change as a result of rising industry shares. This pattern reverted in subsequent years and especially after the 1990s when the contribution of the re-allocation component became strongly negative (McMillan et al. 2014; Timmer et al. 2015). Different to that observed in East Asia, Latin American nations accumulated a large gap in terms of productivity growth in market activities (e.g. distribution and retail trade) which led to high dynamic losses (Timmer et al. 2015).

16.6.1.4 Sub-Saharan Africa

Sub-Saharan African countries display similar patterns to Latin American countries. Apart from a few notable exceptions (e.g. Botswana, Mauritius), these economies also experienced an endemic lack of growth in productivity and living standards in the post-war period. A positive effect of structural change in the region is found only for the earlier periods (1950–1970) and, more moderately, after 1990, while the intervening years are characterized by negative productivity growth rates (in the aggregate) and a strong negative impact of structural change (McMillan et al. 2014; Timmer et al. 2015). The reversal of this negative performance in the 1990s, notwithstanding its (mainly) service-driven nature, has led to some optimistic views on the future of African growth (McMillan et al. 2014). This contrasts with other accounts that have expressed scepticism on the possibility of a service-led growth strategy, emphasizing the presence of large dynamic losses (coexisting with static gains) in service activities (Timmer et al. 2015; de Vries et al. 2015). In a similar vein, Diao et al. (2017) analyse growth booms in Africa and find substantial heterogeneity in structural change patterns during these episodes. Successful and long-lasting expansions (as in Botswana, Ghana, and Mauritius) are associated with fast productivity growth within the modern part of the economy whilst structural change only played a role in Mauritius. On the contrary, growth experiences that raise more concerns (e.g. Ethiopia, Tanzania) are those in which growth-enhancing structural re-allocations are accompanied by stagnant or declining productivity in the modern sector.

16.6.1.5 The BRICS

The acronym BRICS refers to a group of emergent countries that have gained increasing attention over the last two decades. The group includes Brazil, Russia, India, China, and South Africa. These economies now account for a large part of world GDP as well as exports through their increased participation in global value chains. Nevertheless, growth performances among the BRICS are rather heterogeneous both in terms of GDP levels and GDP per capita. The volume by Naudé et al. (2015) collects a series of contributions addressing various aspects of structural transformation in BRICS. The main insight is that the foregoing heterogeneity maps into different structural trajectories followed by individual countries. China and, to a lesser extent, India appear to have experienced a significant expansion of capital-intensive manufacturing activities, while Brazil, Russia, and South Africa are instead moving towards resource- and service-based specialization patterns. Clearly, such divergent trajectories reflect different degrees of economic success, with China and India catching up with the world leaders at faster rates than the other BRICS. This broad impression is supported by the shift-share analysis presented in de Vries et al. (2012). The authors report a strong positive contribution of resource shifts between sectors for only China, India, and—to a lesser extent—Russia. In Brazil, the only positive effect of structural change comes from the increasing formalization of the economy.

16.6.2 Productivity Decomposition using Sectoral Innovation Classes

Notwithstanding several attempts to decompose aggregate productivity into idiosyncratic sectoral components, the criteria used to build sectoral aggregates seem to overlook the results from the literature on sector-specific innovation patterns discussed in Section 16.4. A notable exception is that of Castaldi (2009) which combines the shift-share approach and a sectoral innovation taxonomy. Besides the standard distinction between agriculture, services, and manufacturing (McMillan et al. 2014), some papers propose discriminating also between ICT activities, market, and non-market services (Inklaar et al. 2005; Timmer & van Ark 2005; Inklaar et al. 2008; van Ark et al. 2008; Jorgenson & Timmer 2011). Here instead we directly consider the insights from innovation scholars emphasizing the diversity of technical change patterns at the sectoral level. More specifically, we use Castellacci's taxonomy presented in the previous section to isolate the contribution of sectors characterized by different innovation patterns. Since the taxonomy acknowledges the diversity of user-producer relationships across sectoral classes it also allows us to make some conjectures on the potential co-evolutionary processes existing among them. This implies a relevant advantage since the shift-share analysis based on more standard classifications offers little to say in terms of external effects and interactions across sectors.

Table 16.4 displays details on the classification used which is taken from Castellacci (2008). In particular, it distinguishes between: advanced knowledge providers (ADVknowl); mass production goods (MASSprod); supportive infrastructure services (INFRAserv); and personal goods and services (PERSgoods&serv).

Let us start by plotting the evolution of labour productivity for each sectoral class in seven major regions (Figure 16.6). The data reveals large cross-country heterogeneity in sectoral productivity trajectories. Canada, for instance, has managed to develop a dynamic infrastructure service sector but also exhibits disappointing performances in the other three categories. The sluggish dynamics in the knowledge-providing sector may well account for the lack of growth in more supplier-dominated activities such as mass production and personal goods or services. On the contrary, in Asian countries and the United States improvements in infrastructure services are also accompanied by gains in the ADVknowl group possibly pointing at a co-evolutionary process between the two categories. Similarly, the mass-producing goods industry closely evolves with the ADVknowl and INFRAserv classes as it largely draws on technological advances from both sectors. Such joint dynamics break down only in Japan and partially in the Republic of Korea as a result of the 2007–2008 macroeconomic crisis which largely hit industries in the MASSprod area. Europe, instead, has performed relatively well in both infrastructure and mass production sectors but is also

Table 16.4. Description of sectoral innovation classes as in Castellacci (2008)

Description	**Abbreviation**	**NACE Rev. 2 codes**
Advanced knowledge providers(*including electrical and optical equipment; machinery and equipment n.e.c; IT and other information services; professional, scientific, technical, administrative and support service activities*)	ADVknowl	26–28; 62–63; M–N
Mass production goods(*including coke and refined petroleum products; chemicals and chemical products; rubber and plastic products, and other non-metallic mineral products; basic metals and fabricated metal products, except machinery and equipment; transport equipment*)	MASSprod	19; 20–25; 29–30
Supporting infrastructure services(*including wholesale trade; transport and storage; postal and courier activities; telecommunication; financial and insurance activities*)	INFRAserv	45–46; 49–52; 53; 61; K
Personal goods and services(*including food products, beverages, and tobacco; textiles, wearing apparel, leather and related products; wood and paper products, printing and reproduction of recorded media; retail trade; accommodation and food services*)	PERSg&s	10–18; 47; I

Source: Authors' elaboration based on Castellacci (2008).

characterized by stagnant productivity in knowledge-providing activities. Finally, apart from China, personal goods and services display low growth rates and their patterns are generally disconnected from those in other activities.

We can now compute the contribution of the four sectoral innovation classes employing the shift-share analysis pioneered by Fabricant (1942). Productivity is decomposed according to the following formula:

$$\Delta P(t_0, t_1) = \sum_{i=1}^{n} \Delta P_i(t_0, t_1) \times \theta_i(t_0) + \sum_{i=1}^{n} \Delta\theta_i(t_0, t_1) \times P_i(t_0) + \sum_{i=1}^{n} \Delta\theta_i(t_0, t_1) \times \Delta P_i(t_0, t_1) \quad (2)$$

where P and θ denote sectoral productivity levels and employment shares respectively, while the Δ operator represents changes between t_0 and t_1. The equation shows that sectoral contributions can be further decomposed in three components. The first term accounts for productivity advancements within single sectors holding constant initial employment shares. The second and the third terms instead refer to static and dynamic re-allocation effects and therefore they pin down the contribution of structural change, i.e. whether it is growth reducing or growth enhancing.

Figures 16.7 and 16.8 display the results of the decomposition for Asian and North American countries vis-à-vis Europe.[22] The analysis is broken down into two sub-periods (2000–2007 and 2007–2014) to consider the effects of the Great Recession. A first striking pattern concerns the relatively country-invariant rankings across sectoral groups. More knowledge-intensive classes (ADVknowl and INFRAserv) tend to show higher contributions while, as expected, the production of personal goods and services shows the lowest dynamism. Activities associated with mass production like science-based and

[22] Results for individual countries are instead reported in the working paper version of the chapter (Appendix B).

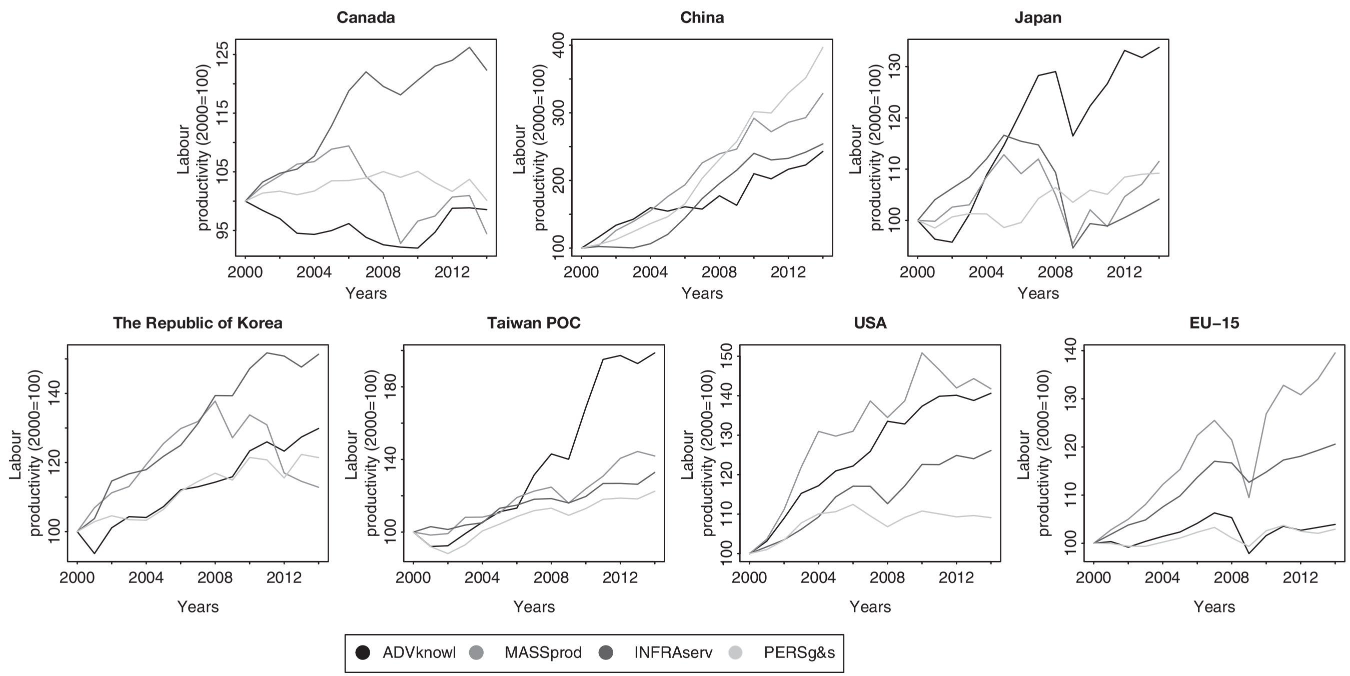

Figure 16.6. Labour productivity dynamics by sectoral innovation classes
Source: Authors' elaboration

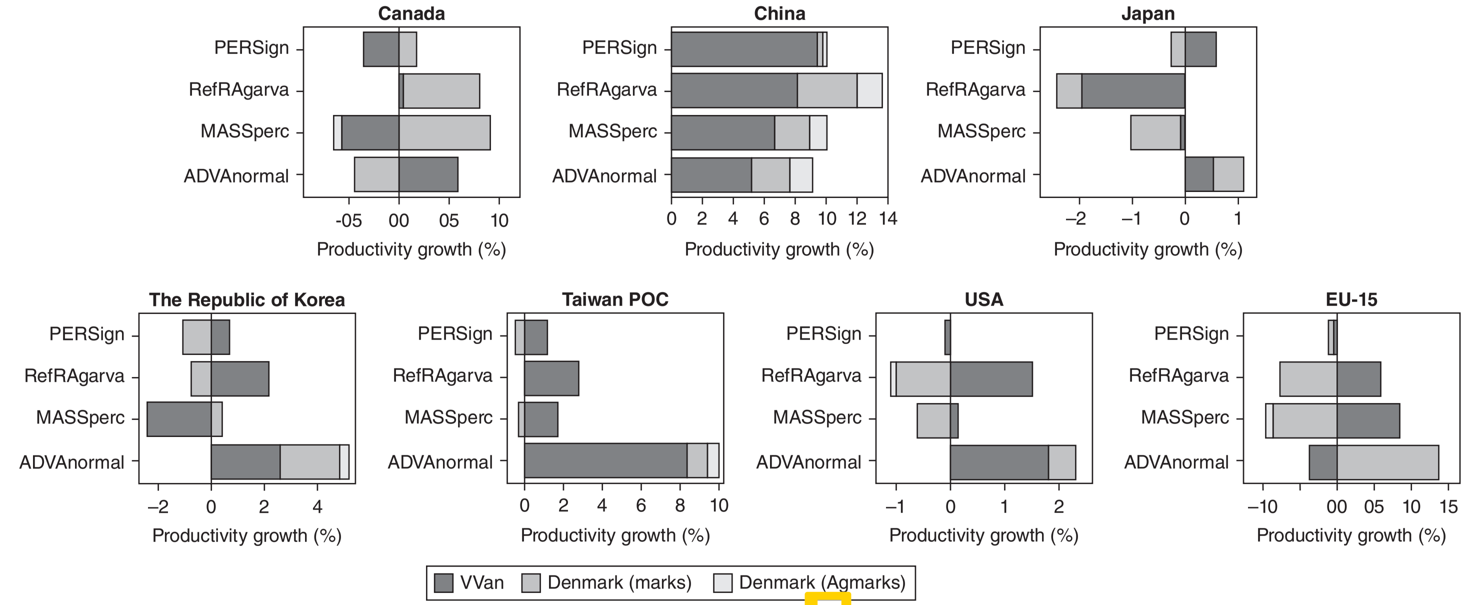

Figure 16.7. Productivity decomposition by sectoral innovation classes (2000–2007)
Source: Authors' elaboration

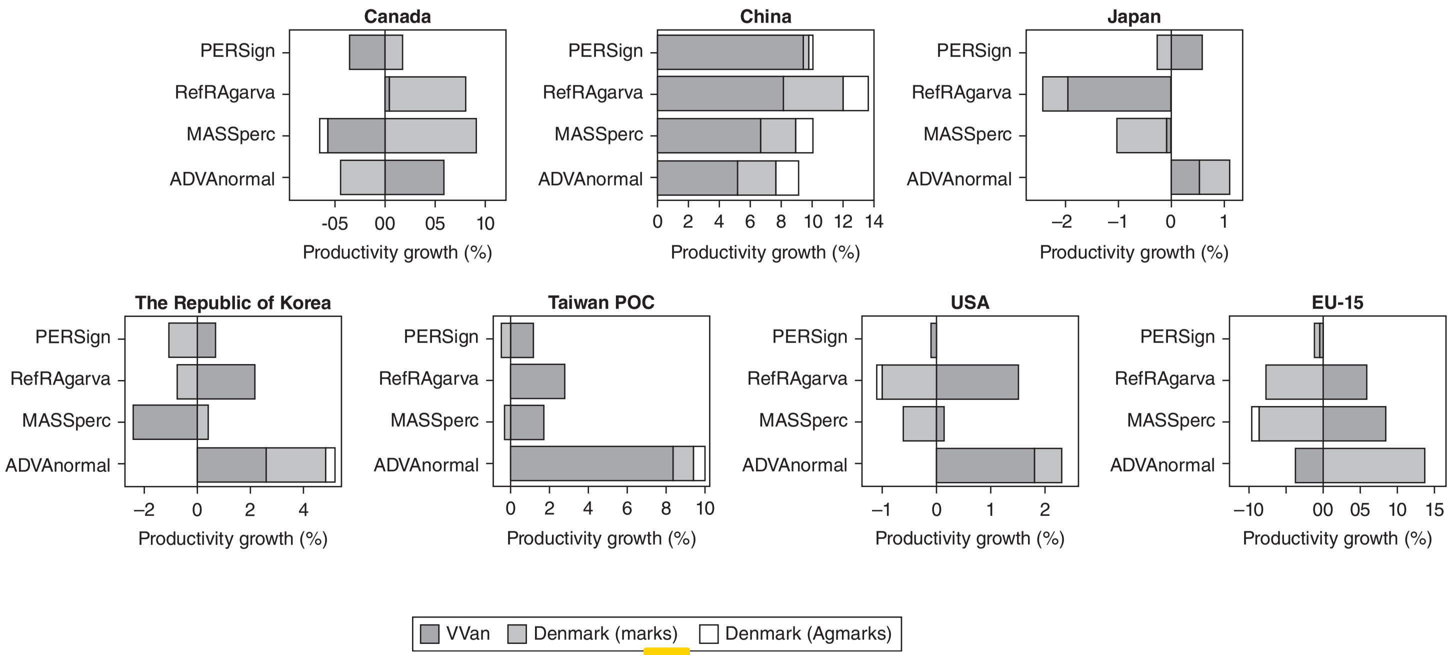

Figure 16.8. Productivity decomposition by sectoral innovation classes (2007–2014)

Source: Authors' elaboration

scale-intensive manufacturing play a role especially in China and the Republic of Korea which are large exporters in these areas. In line with other contributions, we find that the within-class productivity gains generally provide the highest contribution to overall growth. However, results also suggest strong positive gains associated with structural change towards advanced knowledge providers in Asian countries and partially in Europe. Such positive effects cannot be captured by analysis that look only at the aggregate impact of structural change as they are often compensated by changes in the opposite directions from other sectors. Indeed, China is the only country in which the structural change component displays a positive sign for each sectoral category. This is not surprising since, as already discussed, the scope for achieving productivity gains through re-allocation is stronger during phases of rapid catching up. On the contrary, in countries at higher development levels, opportunities for growth-enhancing structural change seem to be associated exclusively with knowledge-providing activities such as IT services, technical consultancy, and specialized suppliers of machinery. A potential explanation for this pattern could be that many of the ICT-related industries are in the early stages of their lifecycle and thus display large potential for increasing their relative size and productivity.

Also interesting is the comparative performance of the United States vis-à-vis Europe. Consistent with other empirical studies our results indicate that a large part of the differential productivity growth among the two regions is explained by the gap (around 3 per cent) in the within component of knowledge- and ICT-intensive areas.

Some of the foregoing results survive the impact of the global financial crisis (Figure 16.7). First, the effect of the crisis is primarily found in the general slowdown of productivity within groups. The ADVknowl and INFRAserv categories appear to be less hard hit (with the exceptions of Europe and Japan) as they both exhibit relatively lower losses in within-sector productivity growth. Moreover, the larger room for growth-enhancing structural change in the ADVknowl group is confirmed also for the period 2007–2014 together with European vulnerability in these particular activities, as reflected by the negative within component.

16.7 Conclusion

The relationship between structural change, technical progress, and aggregate productivity growth has been at the core of several insightful conceptualizations of the process of modern economic growth such as those of Kuznets, Rostow, Dahmen, and neo-Schumpeterian authors such as Freeman, Louçã, Perez, and von Tunzelmann.

In this chapter we contributed to this literature along various dimensions. First, we showed that the conjectures on the secular movements in the sectoral composition of the economy (i.e. the Petty-Clark law) are supported by the data. Second, the chapter provides an extensive review of the contributions linking structural change and sector-specific patterns of innovation to aggregate productivity growth. Finally, an empirical exercise merging shift-share analysis and sectoral innovation taxonomies has been presented. The results from the latter confirms that successful catch-up experiences (e.g. China) largely draw on structural transformation as a source of productivity growth. In advanced countries, instead, knowledge-intensive activities still provide wide margins for achieving productivity gains via both sectoral re-allocations and within-sector technological advances.

At the methodological level, our analysis suggests that an important direction for further research is to move towards more disaggregated accounts that can capture both the sectoral heterogeneity of technical advance and the structure and transformation of the economic and technological linkages between industries. A promising step in this direction is made in this volume by Haraguchi & Amann (Chapter 12, this volume) who analyse productivity patterns for various manufacturing subsectors.

Another significant stream of literature which is relevant for this discussion is the empirical mapping of the diversity of patterns of innovation at the sectoral level carried out by scholars such as Pavitt, Malerba, and Orsenigo since the mid-1980s. This literature has made a fundamental contribution in enhancing our understanding of the factors affecting sectoral patterns of innovative activities and of the life cycle of sectors. In this perspective, an important direction for further research will be to connect this detailed understanding of innovation at the sectoral level with the study of the contours of structural change and economic growth.

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