

Manufacturing Regimes and Transitional Paths: Lessons for Industrial Policy

Patrizio Bianchi and Sandrine Labory

Abstract

This paper argues that structural approaches to the analysis of economic systems provide useful theoretical insights for the definition of industrial policy. In particular, radical structural changes represent 'industrial revolutions' between manufacturing regimes. This paper addresses industrial policy as a policy of transitional (medium-term) dynamics. We analyse industrial revolutions, from the first to the on-going fourth industrial revolution, and discuss both the structural changes implied, namely the shift between manufacturing regimes, and the implications for industrial policy.

Keywords: industrial policy, structural changes, manufacturing regimes, transition.

JEL codes: L52, L23, O30.

1. Introduction

The literature on industrial policy has been consistently growing in the last decades (Rodrik, 2004, 2008; Chang, 1994, 2010; O’Sullivan et al. 2013, Bianchi and Labory, 2006, 2011; Bailey et al. 2010; Stiglitz and Lin, 2013; Noman and Stiglitz, 2016). This has reflected a concern of policy-makers with the capacity of industries to implement the structural changes necessary to adapt to important transformations in the competitive context, resulting from changes in the global market, industrial and technological landscape. The literature has primarily been empirical, analysing industrial policies carried out by various countries in different periods and deriving policy recommendations for developing countries (Amsden, 1989; Wade, 1990; Lall, 2006; Cimoli et al., 2009), as well as mature industrial economies (Block and Keller, 2009; Berger, 2013; Andreoni, 2016)

As a result, while some indications on the way in which industrial policy should be designed and implemented have been provided, theoretical developments on industrial policy remain mainly focused on the proposition of policy rationales anchored around the idea of market failures. A number of contributions, in particular those building on (i) evolutionary economics (Dosi, 1988; Nelson and Winter, 1982; Lee, 2013); (ii) classical development economics and structuralist schools (Hirschman, 1958; Chang, 1994; Lin and Chang, 2009; Andreoni and Scazzieri, 2013; Andreoni and Chang, 2016); (iii) Marshallian analysis of industrial clusters and policies (Bianchi and Bellini, 1991; Andreoni et al., 2016; Becattini et al, 2009 for a review) have challenge the mainstream “market failure” paradigm along different research lines. These include the analysis of systemic and network failures, strategic failures, coordination problems and structural dynamics issues (see Bianchi and Labory, 2011, for a review).

In this paper, we argue that structural approaches to the analysis of production systems provide distinctive and useful theoretical insights for the definition and analysis of industrial policy. For this purpose, we take the view that industrial development is essentially a process of *productive transformation*, led by the expansion of collective capabilities (Andreoni and Chang, 2016). In this view, the analysis of production processes in relation to the market is key, together with the learning processes implied by the associated structural changes of production structures. We claim that the multi-dimensional character of productive transformation has important implications for industrial policy. In particular, we argue that, when substantial (radical) structural changes take place, industrial policy can be considered as a policy of the transition between different *manufacturing regimes*, namely between

prevailing modes of organizing production in manufacturing processes. (see below).

The conceptual apparatus of traverse analysis (Hicks, 1973; Lowe, 1976; Hagemann and Scazzieri, 2009) is useful in addressing attention to the adjustment problems an economic system has to overcome when capital structures (consisting of financial capital, machinery, and human capital) move from one manufacturing regime to another, in particular with respect to transitional (medium-term) dynamics. Of special relevance in this context is the different timing of adaptation along the different dimensions of productive transformation. An industrial policy favouring structural changes must take the timing issue into account by being comprehensive, in the sense of correctly identifying the transformations to be triggered and of including policies favouring the coherent adjustment of all parts of the economic system. We argue that such a comprehensive industrial policy should nowadays emphasise, besides action promoting innovative processes, training and education because the adjustment of human capital (also in the form of very specific production, technological and organisational capabilities) is of central importance in the transition between manufacturing regimes that is currently taking place.

This paper is organised as follows. Section II argues that industrial policy is a policy of transition, which accommodates or orientates industrial development during the shift from one manufacturing regime to another. We then examine the dynamics of manufacturing regimes associated with the different industrial revolutions, as this is where the roots of structural changes lie (Section III). Here the current and much debated fourth industrial revolution is also considered. The industrial policies associated with different manufacturing regimes are addressed in Section IV. This section argues that structural approaches to production analysis (Landesmann and Scazzieri, 1996; Scazzieri, 2014; Andreoni, 2014; Andreoni and Scazzieri, 2014;), especially when learning processes are considered, are needed to understand the effects of structural changes and to design appropriate industrial policies. Section V concludes the paper by proposing a blueprint for industrial strategy appropriate to the current transition between manufacturing regimes.

2. Industrial Policy as Strategy for Transition

We define industrial policy as policy aimed at promoting structural changes in productive sectors of the economic system. This means promoting learning and adaptation that are necessary when the competitive context changes, due to an increase in the extent of the

market, the entry of new players or exit of old ones, and / or technological progress that make new products and production processes feasible (Bianchi, 1984).

This definition highlights that industrial policy is really about the dynamics of the economic system. It may address particular market failures but is more fundamentally about the shifts between different stages of a particular manufacturing regime, or the shifts from one manufacturing regime to another.

A manufacturing regime is a prevailing production system, such as craft production before the first industrial revolution or the mass production system in the 20th century. Production systems are methods for organising production, of which major characteristics can be identified that are common to firms in various industries. For instance, in the mass production system firms divided the production process into numerous phases, each carried out by workers performing simple and repetitive tasks, for which low levels of skills was sufficient. The mass production system was therefore associated with particular social and economic institutions: systems of labour market regulation, of education and training, and of corporate governance.¹ The next section analyses manufacturing regimes in more details.

Industrial policy requires that policy-makers have a capacity both to define a vision of industrial development, namely to choose a particular development path, and to implement a set of different but coherent actions that provide the conditions for the movement of the economic system towards the specific path.

Structural change is a multi-dimensional process (Kuznets, 1973; Abramovitz, 1995; Andreoni and Scazzieri, 2014; Andreoni and Chang; 2016). It involves the introduction of new technologies, new production systems, and new skills in the labour force. Hence the adaptability of the labour force, namely its capability to learn new skills, is an essential factor for structural changes to take place. New knowledge and competencies may be required, implying the need for vocational training. New sectors might emerge, implying institutional change and new regulatory standards (product standards, protection of intellectual property rights, contract law, and so on). Thus structural change generally requires institutional change. This might create systemic failures as institutions and productive sectors may change at different speeds.

One particular problem is the very long timing needed to adapt the skills provided in the

¹ Hall and Soskice (2001) define them as social systems of production, to which the literature has paid attention in the 1980s and 1990s (for instance Piore and Sabel 1984, Dore 1986, Boyer 1990).

⁴ Nelson 1993; Hollingsworth et al. 1994; Herrigel 1996; Hollingsworth and

⁵ Boyer 1997; Edquist 1997; Whitley 1999

educational system. The change of educational system requires a generation to take full effect: only pupils having performed their whole schooling in the new system will be fully prepared for the new skills. In addition, teachers have to be trained to be able to transmit new knowledge and skills to their students. The coherence and alignment between the strategies of actors and institutions are therefore key to favour structural change (Bianchi and Labory, 2011).

The transitional paths of a dynamic economy are characterized by the coexistence of system components with different speeds of adjustment. While mainly focused on transitions between different system equilibria, traverse analysis provides some theoretical tools for identifying the conditions to be fulfilled for the economy to move from a given initial trajectory to a different stipulated trajectory (Hicks, 1973, Lowe, 1976). According to Christian Gehrke and Harald Hagemann (1996), traverse analysis examines how an economy, which had originally been in steady-state equilibrium, may evolve to a new equilibrium growth path following a disturbance such as technological progress. The analysis therefore considers two aspects, namely the conditions for the economy to embark and remain on a balanced (full employment) steady-state growth path and how it can shift to a new one. In particular, 'when the problem of structural change arises, the importance of the industrial structure and physical bottlenecks in production immediately comes to focus' (Gehrke and Hagemann, 1996, p. 141). The analysis focuses on 'the motions of structural elements, which will transform the initial state into the stipulated terminal state' (Gehrke and Hagemann, 1996, p. 142). The analysis of the traverse has mainly focused on adjustment in the capital stock, namely physical machines, not adjustments in human capital, which is however essential in an industrial policy perspective. Adolph Lowe has paid more attention to the mobility of human capital across jobs (Lowe, 1976), showing that the traverse might be characterised by temporary unemployment (for a treatment of these forms of structural unemployment in developing countries see also Bhaduri, 2006). However, the adjustment of labour in qualitative terms, namely in terms of skill adjustment, is not considered. Both Hicks (1973) and Lowe (1976) consider technological change as the most important stimulus to growth, and they distinguish between the short-run and long run effects of innovations. Lowe shows that the employment effects of process innovations crucially depend on investment behaviour during the transitional phase.

The analysis of industrial policy requires the identification of its goals. Not only does growth matters (that is, to follow a specific growth path), but also what type of growth, that is, along the same growth path or towards new growth paths. Choosing a growth path requires anticipation, understanding structural elements and their changes, and designing an industrial policy that can influence those elements. Here the difficulty is that all parts of the economic system do not necessarily adjust, or they may do so with different timings, so that industrial policy must necessarily be a process whereby actions are monitored and evaluated in the course of its implementation, and accordingly changed if bottlenecks are identified in the process. Hence in order to provide the conditions for effective industrial development one has to examine the roots of structural changes in economic systems. The next sections examine the characteristics of different manufacturing regimes, transitional paths across such regimes, and the relevant options open to medium-term industrial policy.

3. Manufacturing Regimes and Industrial Revolutions

Industrial production is associated with different forms of production organisation, which have dominated specific phases of economic history. In this sense, it is possible to define the concept of *manufacturing regime* as the form of production organisation that prevails in a certain period of industrial production. We may correspondingly identify *industrial revolutions* as major discontinuities in manufacturing regime due to the use of different raw materials, different technologies and organisations of production, as well as social and institutional transformations.

Thus the first industrial revolution is the shift from the manufacturing regime of craft production to the manufacturing regime of the factory system, which introduces the division of labour in the factory. The second industrial revolution is the shift from the factory system to the manufacturing regime of mass production, which pushed the division of labour to the extreme, into very simple tasks that are realised by different workers along the assembly line. The third industrial revolution is shift from the manufacturing regime of mass production to the manufacturing regime of the flexible production system, first introduced by Japanese producers in the 1980s. The fourth industrial revolution is the shift from flexible production to the manufacturing system of smart manufacturing- or digital factory, in which automation increases and machines are linked together by sensors and other devices that allow

communication between the machines, and between the machines and the product being made.

The first manufacturing regime (*craft production*), was characterised by production arrangements in which any given agent (or group of agents) was capable of carrying out all the phases necessary to produce the final good, even if at any given time some agents (or agents' groups) would carry out only certain production phases and not others within the same workshop (Scazzieri, 1993). This manufacturing regime was typical before the industrial revolution that started in the late 18th century. In that regime, production could be increased only by adding craftsmen (or groups of craftsmen), who could realise the different phases of the production process in parallel.

The first industrial revolution results from the introduction of machines in production processes, from the division of the latter into different tasks, and from the specialisation of workers on specific tasks they would carry out sequentially. This transformation led to the second manufacturing regime (*machinery production*). Further specialisation characterizes the second industrial revolution, which led to the third manufacturing regime (*mass production*), in which the production process was divided into elementary tasks that low-skilled workers could perform in sequence. This system, which was initiated by Henri Ford in 1913 (Bianchi, 1991; Labory, 2002), is extremely rigid in that any change in the product would be very time-consuming and costly. This regime allowed the exploitation of economies of scale, with homogenous products produced on very large scale, which could have low price but very little differentiation. Throughout the 20th century differentiation was introduced in the mass production system by multiplying the divisions of the firm and having different divisions and factories dealing with different product varieties (the M-Form introduced by GM in the 1920s, see Chandler, 1982).

From the 1980s Japanese producers, especially in the car industry, introduced a new production model that Womack et al. (1990) called "lean" production system, while Abo (1994) preferred to call it "flexible" production system, which progressively constituted a fourth manufacturing regime (*flexible production*). Production systems became flexible in that they were able to produce partially differentiated products on a large scale, with the possibility to reduce the time to market and therefore more rapidly react to changes in demand or in competitors' strategies. Production processes were still divided in tasks, but

different varieties of the product shared the same production lines, and differentiation arose at later stages of the production process. In this manner economies of scale were combined with economies of scope. In addition, product changes could be implemented without a complete re-organisation of the production process: the basics of the product remained the same (for instance the car body), so that economies of scale were still generated, while differentiation regarded some sub-sequences of the production process or modules. Parts across different products were made common, so that different models could be manufactured on the same line of production for some stages. One principle of this manufacturing regime, originally introduced by Toyota, is “kaizen”, namely continuous improvements, whereby workers were encouraged to identify problems and suggest solution. However, this principle effectively worked only when the production process was organised into sub-lines (Labory, 2002), thus allowing the formation of stocks *between the sub-lines* and reducing time pressure on workers who could also dedicate to problem identification and resolution (see also Frigant and Jullien, 2014). Japanese producers introduced this manufacturing regime due to the specific constraints they were facing in their home market in the decades following WWII. In that period, demand was limited, consumers needed small and cheap cars but with some degree of differentiation. This led Japanese carmakers to adopt organisational arrangements that could allow product variety at low cost, thus combining economies of scale and economies of scope (Womack et al., 1990, Bianchi, 1984). Consumers asked for more variety in Western markets too, and producers explored new production systems in order to meet this request. For instance, automated processes were tried out, but at that time they did not have enough versatility to produce sufficient varieties and therefore were limited to specific phases of the manufacturing process. The concept of the “world car” was tried out, in that some carmakers (for instance, Ford) tried to develop cars that could fit the whole world market, but this proved unsuccessful (Labory, 2002). Robotised production systems eventually made the combination of scale and scope economies possible through the full automation of fabrication stages.

The fourth manufacturing regime has also seen the re-organisation of manufacturing systems along vertically disintegrated global supply chains, each of them characterised by different degrees of modularisation. Changes in the forms of production, in particular its global network expansion, has also led to new forms of flexible production and the diffusion of lean practices across multiple sectors (Milberg and Winkler, 2013; Berger, 2013; Andreoni and Chang, 2016b).

Different technological systems are associated with these four manufacturing regimes. The first industrial revolution is associated with water- and steam-powered technologies that enabled machinery production. . With the second industrial revolution, electricity and various technological innovations converged to allow mass production, as in the automotive industry. Starting from the 1970s, electronics and IT made possible a third industrial revolution. In this context the Japanese producers invented the flexible manufacturing system (FMS), using automation as much as possible in phases characterised by economies of scale.

Manufacturing production is currently experiencing a fourth industrial revolution, with the introduction of cyber-physical systems, whereby complex networks of machines, physical goods, virtual objects, computing and memorisation structures, communication devices (such as video and sound), and energy containers interact among themselves and with economic agents (Brynjolfsson and McAfee, 2014; Schwab, 2016; OECD, 2015). This transformation leads to a merger (convergence) between the real world of industrial plants and the virtual world, namely the IOT (the Internet of Things). All components and technological equipment (sensors, GPS, others), which can be incorporated in physical objects and machines, ensure the interface between the physical and the virtual world. In this manufacturing regime, the product is able to “communicate” with machines in order to “tell them” what to do. Machines can exchange information and modify their own “behaviour” on the basis of the received inputs, to memorize instructions and therefore learn from the digital interaction. The consequence is enhanced connectivity and interdependence not only between workers and machines, but also between the machines themselves.

This is helped by cloud computing, namely open platform and architecture used in industrial processes for the modelling, simulation, planning, and analysis of data coming from sensors used in productive processes. This system allows real time interaction between market dynamics, product development, and manufacturing, so that production arrangements can rapidly change leading to a different variety of goods. Differentiation substantially increases, even allowing product customisation. The manufacturing regime emerging from the fourth industrial revolution is a *mass customisation* process. In this case, the relationship between the division of labour and the extent of the market changes and becomes extremely close: division of labour and ‘division of product’ get intertwined. . Each consumer can send requests for a particular product specification to the digital factory, which answers by adapting the machines and robots and allowing rapid production of the customised product.

The fourth industrial revolution has deep implications in terms of adjustment of the capital structure. In particular, the human capital needed for production tends to concentrate on the upstream and downstream productive phases, since robots and machines carry out the 'material' manufacturing phase. Product R&D, prototyping, and marketing / commercialisation become key phases where human capital is needed, because these phases are the most intensive ones in knowledge and knowledge creation. In particular, in a globalising economy where competition becomes more intense and extended to many different markets in the world, the knowledge content of products increases because product innovation becomes a key source of competitive advantage. In the mass customised manufacturing regime, this tendency is accentuated, since the source of firms' competitive advantage mainly resides in their capacity to provide real-time answers to consumers' requests in terms of product characteristics.

3.1 Manufacturing regimes transitions: work done and work to be done

The transition from a manufacturing regime to another is thus associated with changes in technology systems. However, at the most fundamental level, both changes in manufacturing regimes and technologies are both response to changes in demand, specifically the need to adjust production with respect to product "volumes" – low, medium and high – and product "variety" – low, medium and high. And of course, this adjustment is not immediate and costless. This fundamental problem has been at the core of production and firm theories since Adam Smith's first articulation of the idea of "division of labour"².

Adam Smith (1776) argued that 'the effects of the division of labour, in the general business of society, will be more easily understood by considering in what manner it operates in some particular manufactures' (WN, I, 1, p. 4). An important distinction is that between organic and heterogeneous manufacture. Products can be made by simple mechanical combination of partially independent goods (heterogeneous manufacture), or by a sequence of processes and tasks that are reciprocally related (organic manufacture). In the Fordist production system, production is divided into simple tasks that are made organic in a rigid process. In a flexible manufacturing process there is a split between heterogeneous and homogeneous components. Certain production phases are made heterogeneous in order to allow product differentiation, while other phases remain organic in order to continue exploiting economies

² Developments of this idea can be also found in foundational contributions by Edith Penrose (1959) and Alfred Chandler (1990)

of scale. In mass customised manufacturing, the production system allows such a combination of economies of scale and scope to be pushed even further, as machines continuously adjust to the specifications indicated in the sensors of each product. Productive efficiency derives from capacity to adjust production to changing customers' specifications, not from volumes of stocks of realised products. Smith's distinction between 'work done' (products actually made) and 'work to be done' (products that may be made) is relevant in this connection. In discussing the failure to adjust production to changing demand in the case of a public mourning raising the demand for black cloth (*Wealth of Nations*, I.7, p. 52), Smith called attention to the fact that in this case the market would be over-stocked with coloured cloths, and under-stocked with black cloth. This mismatch between product volumes/variety and demand signals that work done is not adequate (there is too much coloured cloth). On the other hand, work to be done would be adequate provided the work force originally employed in making coloured cloth could be switched to produce black cloth. .

The distinction between work done and work to be done is useful to distinguish between different manufacturing regimes is clear. The Fordist system (mass production manufacturing regime) is centred on work done, as the factory produces goods of given specifications that are then sold on the market. Production is rigid and takes time to adjust to changing demand. The flexible manufacturing regime introduces capacity to adjust to changing demand, as work done can be different from work to be done. In the mass customisation manufacturing regime, products can be customised at low cost and the whole competitive advantage of producers is based on work to be done.

Volume	High	Mass production		Customised mass production
	Medium		Flexible production	
	Low			Customised individual production (craft)
		Low	Medium	High
	Variety			

Figure 1. Transitions between Manufacturing Regimes

Work done is the flow of physical goods in transformation, while work to be done is the flow of production-related information. In the mass customization manufacturing regime, value added is primarily generated from the control and management of the work to be done, namely of the information flows related to production and generated from 'big data' deriving from close interaction with markets. In this case, the manufacturing system is coordinated and managed through sensors that connect machines to markets. This generates a large volume of data that must be analysed to deliver customised products. Figure 1 shows shifts in manufacturing regime according to the degree of product differentiation and economies of scope (horizontal axis), versus production volume and economies of scale (vertical axis).

3.2 Manufacturing regimes and competition

An important factor for transition in manufacturing regime is technological change. New technologies introduced in the first and second industrial revolutions induced the shifts from craft production to the factory system, and subsequently to the mass production system. Today, technological progress, including smart manufacturing and IOT, is making new production organisations feasible, leading to mass customisation. However, there are other

factors to the shift in manufacturing regime, linked to market competition. On the one hand, demand may change. Thus, consumers started to ask for more product variety in the 1970s and 1980s, leading to the need of combining economies of scale and economies of scope, which the Japanese production system allowed. On the other hand, competition may intensify, with the entry of new rivals. This was also the case in the shift from the mass to the flexible production system, since Japanese producers became direct competitors in the American and European markets in the above-mentioned decades.

As outlined in Bianchi (1991), the change in manufacturing regime in turn has an impact on market competition. A firm's market power results from the relationship between production organisation and the extent of the market, that is, market demand and strategic interactions between rivals. The shift from the mass production system regime to the flexible production manufacturing system is associated with important changes in market structure. The number of rivals reduced: while in mass production, a few large producers co-existed with smaller firms occupying market niches (such as luxury cars), in the flexible production manufacturing system, the number of smaller firms declined, because the new production system allowed to produce variety at low costs. This means that the product variety formerly achieved and hence the variety formerly produced by niche firms could be integrated into the production of larger firms. The larger firms thus increased their range of products and especially product variety. In the car industry, for instance, the number of producers shrank from 100 to 35 between the 1970s and 1980s (Bianchi, 1991). While the world car market was characterised by different oligopolies (in the USA, in Europe and Japan), this fragmentation subsequently decreased and contributed to a certain degree of integration into a single worldwide oligopoly, since carmakers started to more actively sell in each other's markets (Japanese and European producers in the USA, Japanese and American producers in Europe). This entailed a shift from imperfect competition in restricted markets (under the mass production regime) to oligopolistic competition in a wider market (under the flexible manufacturing regime). Today mergers and acquisitions are observed in many sectors, suggesting changes in market structure. In the car industry, for instance, existing producers are forming new alliances (e.g. such as Mitsubishi and Toyota), reinforcing them (e.g. such as Renault and Nissan), and even merging, as in the case of FIAT and Chrysler. In the meantime, new entrants appear, introducing substantial product innovations, such as the self-driving car (e.g. Google and Tesla).

Based on the analysis of manufacturing regimes (and related technology systems), their transitions, and their effects on competition, the next section discusses the implications of changing manufacturing regimes for industrial development and industrial policy, with specific reference to the problem of developing human capital and skills for changing production structures.

4. Manufacturing Regimes, Skill Development and Industrial Policy

Bianchi and Labory (2006, 2011) analysed industrial policies implemented in different countries (in Europe, the USA and Asia) since 1945. They identified different phases of industrial policy, corresponding to different dominant manufacturing regimes. During the heydays of mass production after WWII and up to the 1970s, industrial policy was selective and interventionist, in the sense that governments directly intervened in markets, picking winners and often being producers themselves, through state-ownership of businesses. The crisis of the 1970s progressively led to the diffusion of the flexible production manufacturing regime, but also to a new approach to industrial policy, whereby the state no longer directly intervened in markets but preferred providing the conditions for industrial development (such as infrastructure, training and education, and basic research) and ensuring fairness of competitive environment. The focus was on 'horizontal measures' applied to all sectors without selectivity, including measures such as support to small and medium-sized enterprises, or clusters or R&D innovation programmes.

Since the early 21st century, the pressure for structural changes induced by globalisation (hence by changes in market conditions) and technological innovations triggered a new phase of industrial policy, in which a variety of measures could be considered if they could sustain structural changes.

The structural analysis of manufacturing regimes developed in the previous section suggests the need to formulate appropriate industrial policies focusing on productive structures in transition from one manufacturing regime to another and, in this respect, the necessary adjustment in terms of human capital.

The analysis of productive structures has been carried out with different focuses:

- i) The division of the production process into different tasks and the analysis of different organisational modes (an approach that goes back to Smith, 1776);
- ii) The analysis of the active elements (agents) that bring the productive transformation about. In this case, the agents' capabilities and their utilization over time (Babbage, 1832; Georgescu-Roegen, 1970);
- iii) The transformation of materials involved in the production process (Lowe, 1976);
- iv) The relationship of productive structures to market characteristics and firms' strategies (Bianchi, 1991; Bianchi and Labory, 2011).

In the structural approach to production, productive activities are considered as a major source of uneven change in the dynamics of economic systems (Pasinetti 1981, 1993; Quadrio Curzio, 1986; Quadrio Curzio and Pellizzari, 1991; Scazzieri, 1993, 2014; Landesmann and Scazzieri, 1996; Andreoni, 2014). Different patterns of structural dynamics emerge from the interaction of three fundamental components of production processes: tasks, agents and materials-in-process. Structural dynamics involve transformations in the way these elements are structured and coordinated. In particular, certain elements may persist, or they may create bottlenecks in the capacity of the system to change. New elements may be introduced, implying the need for new skills for agents, as well as new coordination arrangements. According to Landesmann and Scazzieri (1996, p. 3), 'structural economic dynamics may be defined as the analysis of economic transformations that explicitly account for the relative persistence of certain elements or relationships of economic structure while other elements or relationships are subject to change. Structural change may arise in single industries or in the whole economy.'

This framework highlights the coexistence of features of persistence and features of change. Different sectors and economies may be characterized by different patterns of structural change because tasks, agents and materials-in-process may alter at different speeds across sectors and economies.

Andreoni and Scazzieri (2014) argue that the main drivers of structural changes in production are increasing and decreasing returns. Increasing returns are associated with division of labour, allowing specialisation and complementarities (see also Scazzieri, 2014). Decreasing returns result from constraints in the evolution of productive structures. Andreoni and

Scazzieri argue it is possible to implement structural policies that favour increasing returns and avoid decreasing ones, acting on two levels, namely the technological level and the institutional level. This may be achieved, at the former level, by policies supporting technological complementarities, while institutional complementarities may be achieved by policies promoting coordination across production units, when this can trigger complementarities across processes.

There are two main dimensions of production processes: the technical dimension, which consists of the set of feasible combinations of materials according to physical and engineering laws, and the organisational dimension, which consists of the coordination mechanisms used to assign tasks to productive agents. As a result, 'any given process of production may be described in terms of the duality between the domain of structurally feasible tasks and that of organisational arrangements' (Andreoni and Scazzieri, 2014, p. 1397). This means that any type of structural change must be analysed by looking at its effects on the relationship between the technological and organisational domains at different levels of aggregation, that is, from individual production units to the whole firm or industry.

Learning processes arising within specific production structures are a central influence in determining the development of new productive configurations (structural changes). These processes emerge from the capabilities of the agents involved in the production process, that is, both from the workers engaged in the various phases of production and from the engineers designing the overall process. However, learning does not only depends on these capabilities, essentially the technical knowledge and the routines providing coordination in the organisational arrangements. Similarities, complementarities and bottlenecks in production structures are fundamental in triggering "structural learning" dynamics (Andreoni, 2014). Indeed, production structures also determine the type and modalities of interactions and communication between the agents of the productive process, and therefore knowledge creation and learning. Finally, existing productive structure determines both the capacity used to make mechanical artefacts and the capabilities used by productive agents in their activities.

In the mass production manufacturing regime, learning is limited as tasks are elementary and repetitive and product innovations are not frequently introduced. In the flexible manufacturing regime, learning can occur and is encouraged both in the technological and the organisational domains, to avoid or overcome bottlenecks and/or to exploit opportunities. In

the mass customised manufacturing regime, structural learning is continuous and inherent in the interaction between machines, as well as between machines and humans. More recently, online platforms represent a new intermediary between producers and consumers in the mass customised manufacturing regime that is emerging from the industrial revolution currently on the way (see Martens, 2016, for a review).

Learning, however, does not only arise within existing productive processes. New technologies, changes in demand, or changes in competition structures (such as those associated with the emergence of new competitors), can trigger the introduction of new products and new production processes. Changes in production processes may reflect changes in market structure. Second, different types of structural change can be distinguished according to the type of innovation.

In this perspective, it is important to distinguish between incremental and radical structural change. Learning arising *within* existing production processes, that is, learning exploiting increasing returns or avoiding decreasing returns, leads to incremental innovations, which in turn generates incremental structural changes. In contrast, the introduction of new technical equipment or new organisational arrangements often leads to radical innovations and radical structural changes. The transition between manufacturing regimes is a prime example of the latter process. Incremental structural changes are likely to sustain growth along a given dynamic trajectory. Radical structural changes shift the economy to a different growth path.

The transition from one manufacturing regime to another requires a radical structural transformation (industrial revolution). This transformation may involve the switch to different arrangements on some or all dimensions of the production process. However, there might be obstacles in the existing economic structure that prevent the transition. We view industrial policy as the primary instrument for removing those obstacles. In this connection, time is the crucial element of adjustment, as the different capitals involved in production processes (machinery, human capital, and financial capital) have different timings of adaptation. For example, machines are changed quickly as soon as new technology is available, while human capital takes more time to learn new knowledge and competencies required for the new manufacturing arrangement. The asymmetry in the adjustment speeds of the different elements of the production process is a fundamental characterizing feature of transitional paths in the production domain (Hicks, 1973). However, the coordination of changes that take place at different speeds for different types of capital may not be

compatible with the adjustments triggered by market price adjustments: If unsuitable prices are adopted, and adhered to for long, unsuitable techniques will be adopted; the problem of getting into equilibrium will be further complicated, and the approach to equilibrium will be retarded” (Hicks, 1985, p. 143). A functioning price mechanism alone is not sufficient to ensure a move to the new equilibrium, or better, to enter a different growth path. It is therefore important to understand the intertemporal complementarity characteristics of production processes and their determinants in order to identify which policy measures might be necessary to trigger the switch to the new manufacturing regime.

For example, workers are likely to be displaced from labour-saving innovative sectors to other sectors. However, wage differentials across sectors would not be sufficient to achieve the transition, as labour mobility will be constrained by the skill requirements for the new jobs. In this case, a comprehensive industrial policy intervention may be needed to provide training and education aimed at adjusting workers’ skills (see below). To sum up, the policy time frame and the synchronisation of policy measures along transformation cycles (Andreoni, 2016; Andreoni et al., 2016) are of central importance. A key aspect of industrial policy for transitions between manufacturing regimes is therefore the alignment of adjustment timings to make the overall transformation coherent and effective.

5. Concluding remarks

The design of industrial policy defined as policy promoting structural change should be based on the analysis of the production system and of the opportunities and constraints offered by new technologies or other factors of structural change (such as increasing extent of the market). Industrial policy can address both incremental and radical structural changes. Radical structural changes imply more profound transformations in the economic system (changes of manufacturing regime), so that industrial policy should be considered as a set of complementary and integrated policies, including policies in the education and training fields, as well as policies aimed at ensuring access to finance for industries in need of large investments. Education systems are central to the design and implementation of industrial policies for radical structural change. For education systems have to adapt to provide the necessary skills and competencies in order both to allow the alignment of the different economic actors’ perceptions, and to favour relative specialisations and collective complementarities. In particular, the mass customization regime increasingly requires

integration of science with production, as shown by the creation of National Manufacturing Innovation Institutes in the US in 2014, where researchers from the public and private sectors collaborate with business in order to develop and apply new technologies for products and production processes. To sum up, the objective of industrial policy for transition between manufacturing regimes is not primarily growth but adjustment and adaptation, namely resilience during the traverse. In short, industrial policy for radical structural change could be more appropriately called industrial development policy, thus indicating the necessary dynamics of policy: structural changes require time, and policies have to be defined as processes which evolve through time as implemented measures are evaluated and adjusted if not effective. Industrial development is also a problem of alignment of institutions to changes: particularly of the institutions related to the definition of competencies. As argued by Albert Hirschman (1958), who supported the adoption of differentiated and interlinked policies, society could develop by making the economy more complex, not by complexity reduction that hinders the coherence of the economic system and triggers uneven development.

Acknowledgements

We are grateful to two anonymous reviewers and especially the editors of this special issue for their substantial comments and helpful suggestions.

References

1. Abo, T., 1994, *The Hybrid Factory*. Oxford University Press, New York.
2. Abramovitz, M., 1995, The elements of social capability. In B. H. Koo and D. H. Perkins (eds.), *Social Capability and Long-Term Economic Growth*, pp.19–48. Basingstoke, Macmillan.
3. Andreoni, A., 2014, Structural learning: Embedding discoveries and the dynamics of production. *Structural Change and Economic Dynamics*, 29, 58-74.
4. Andreoni, A., 2016, Varieties of Industrial Policies. Models, Packages and Transformation Cycles. In Noman A., Stiglitz J.E. (Eds.), *Efficiency, Finance and Varieties of Industrial Policies*. Initiative for Policy Dialogue at Columbia: Challenges in Development and Globalization. Columbia University Press, New York, Chapter 9, pp. 245-305.

5. Andreoni, A., Scazzieri, R., 2014, Triggers of change: structural trajectories and production dynamics. *Cambridge Journal of Economics*, 38, 1391-1408.
6. Andreoni, A., Chang, H-J., 2016, Bringing production and employment back into development: Alice Amsden's legacy for a new developmentalist agenda. *Cambridge Journal of Regions, Economy and Society*, doi:10.1093/cjres/rsw029.
7. Andreoni, A., Frattini, F., Prodi, G., 2016, Structural cycles and industrial policy alignment: the private-public nexus in the Emilian Packaging Valley. *Cambridge Journal of Economics*, doi: 10.1093/cje/bew048.
8. Andreoni, A. and Chang, H-J. (2017) 'Industrial policy and the future of manufacturing', *Economia e Politica Industriale. Journal of Industrial and Business Economics*, 43(4), 491-502.
9. Babbage, C., 1832, *On the Economy of Machinery and Manufacture*. London, Charles Knight.
10. Bailey, D., Lenihan, H., Singh, A., 2010, Tiger, Tiger, Burning Bright? Industrial Policy 'Lessons' from Ireland for Small African Economies. In Noman A., Botchwey K., Stein, Stiglitz J. (Eds.). *Good Growth and Governance in Africa. Rethinking Development Strategies*, Oxford University Press, Oxford, Chapter 14.
11. Berger, S., 2013, *Making in America*. Cambridge, MA, MIT Press.
12. Bhaduri, A., 2006, *Employment and Development. Essays from an unorthodox perspective*, Oxford, Oxford University Press.
13. Bianchi, P., 1984, *Divisione del lavoro e ristrutturazione industriale*. Il Mulino, Bologna.
14. Bianchi, P., 1991, *Produzione e Potere di Mercato*,
15. Bianchi, P., Labory, S., (Eds.), 2006, *International Handbook of Industrial Policy*. Edward Elgar, Cheltenham.
16. Bianchi, P., Labory, S., 2011, *Industrial Policy after the Crisis. Seizing the Future*. Edward Elgar, Cheltenham.
17. Boschma, R., 2015, Towards and Evolutionary perspective on regional resilience. *Regional Studies*, 49(5), 733-751.
18. Boyer, R., 1990, *The Regulation School: a Critical Introduction*. New York, Columbia University Press.
19. Brander, J., 1986, Rationales for strategic trade and industrial policy. In Krugman P.R. (Ed.), *Strategic Trade Policy and the New Industrial Economics*. MIT Press, Cambridge MA.
20. Brusoni, S., Malerba, F. (Eds.), 2007, *Perspectives on Innovation*. Cambridge University Press, Cambridge.

21. Brynjolfsson, E., McAfee, A., 2014, *The Second Machine Age. Work, progress and prosperity in a time of brilliant technologies.* New York, W.W.Norton & Company,.
22. Cellini, R., Lambertini, L., 2006, Differential game—theoretical analysis and industrial policy. In Bianchi, P., Labory S., (Eds.), *International Handbook of Industrial Policy*, Edward Elgar, Cheltenham, pp.
23. Chandler, A., 1990, *Scale and Scope: the Dynamics of Industrial Capitalism.* Cambridge MA, the Belknap Press.
24. Chandler, A., 1982, *The M-Form: Industrial Groups, American Style.* *European Economic Review*, 39(1), 3-23.
25. Chang, H-J., 1994, *The political economy of industrial policy.* Macmillan, London.
26. Chang, H-J., 2010, *Industrial policy: can we go beyond an unproductive confrontation.* Turkish Economic Association, Working Paper n. 2010/1, Ankara.
27. Cimoli, M., Dosi, G., Stiglitz, J., (Eds.), 2009, *Industrial Policy and Development. The Political Economy of Capabilities Accumulation. The Initiative for Policy Dialogue Series.* Oxford University Press, Oxford.
28. Dore, R., 1986, *Flexible Rigidities: Structural Adjustment in Japan: 1970-1982.* London and Stanford, The Athlone Press and Stanford University Press.
29. Dosi, G., 1988. Sources, procedures and microeconomic effects of innovation. *Journal of Economic Literature*, 26(3), pp. 1120 – 1171.
30. Foray, D., Lissoni, F., 2010. University Research and Public-Private Interaction. In Hall B.H., N., Rosenberg, (Eds.). *Handbook of the Economics of Innovation, Volume 1*, Elsevier North Holland, pp. 275 – 314.
31. Freeman, C., 1982. *The Economics of Industrial Innovation.* Pinter Publishers, London.
32. Freeman, C., Perez C., 1988, *Structural Crises of Adjustment: Business Cycles and Investment Behaviour.* In Dosi et. al. (Eds.). *Technical Change and Economic Theory*, Pinter Publishers, London, pp. 38-66.
33. Frigant, V., Jullien, B., 2014. Pourquoi et comment la production modulaire transforme l'industrie automobile?. *Revue d'économie industrielle*, n.4, 11-44.
34. Gehrke, C., Hagemann, H., 1996, *Efficient traverses and bottlenecks: a structural approach.* In M.A., Landesmann, R., Scazzieri (Eds.), *Production and Economic Dynamics*, Cambridge University Press, Cambridge, pp. 140-156.

35. Georgescu-Roegen, N., 1970, The Economics of Production, *The American Economic Review*, 60(2), Papers and Proceedings of the Eighty-second Annual Meeting of the American Economic Association (May 1970), 1-9.
36. Hall, P.A., Soskice, D., 2001, *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*. Oxford, Oxford University Press.
37. Hausmann, R., Rodrik, D., Sabel, C.F., 2008. *Reconfiguring Industrial Policy: a framework with an application to South Africa*, CID Working Paper n. 168, Harvard University, Harvard.
38. Hicks, J., 1973, *Capital and Time*, Clarendon Press, Oxford.
39. Hicks, J., 1985, *Methods of dynamic economics*, Clarendon Press, Oxford.
40. Hirschman, A., 1958, *The Strategy of Economic Development*, Yale University Press, New Haven.
41. Kuznets, S., 1973, Modern economic growth. *American Economic Review*, 63: 247–258.
42. Labory, S., 2002, "A Firm's Organisation and Its Implications for Market Performance". *Economia Politica*, anno XIX, n. 2, 259-276.
43. Laffont, J-J., Tirole, J., 1993, *A Theory of Incentives in Procurement and Regulation*, MIT Press, Cambridge.
44. Lall, S., 2006. Industrial policy in developing countries: what can we learn from East Asia?. In P., Bianchi, S., Labory (Eds.), *International Handbook of Industrial Policy*, Edward Elgar, Cheltenham, pp. 79-97.
45. Landesmann, M.A., Scazzieri, R., (Eds.), 1996. *Production and Economic Dynamics*, Cambridge University Press, Cambridge.
46. Lee, K., 2013, *Schumpeterian Analysis of Economic Catch-up*. Cambridge. Cambridge University Press.
47. Lin, J., Chang, H-J., 2009. Should industrial policy in developing countries conform to comparative advantage or defy it?, *Development Policy Review*, 27(5), pp. 483-502.
48. Lipietz, A., 1986. New tendencies in the international division of labor: regimes of accumulation and modes of regulation. In Scott, A.J., Storper, M., (Eds.), *Production, Work, Territory. The geographical Anatomy of Industrial Capitalism*, Allen and Unwin, London, pp. 16-40.
49. Lowe, A., 1976. *The Path of Economic Growth*, Cambridge University Press, Cambridge.
50. Martens, B., 2016, *An Economic Policy Perspective on Online Platforms*, JRC Technical Reports, Institute for Prospective Technological Studies Digital Economy Working Paper n. 2016/05, European Commission.

51. Milberg, W., Winkler, D., 2013. *Outsourcing Economics*. Cambridge, Cambridge University Press.
52. Nelson, R., Winter, S., 1982. *An evolutionary theory of economic change*, Harvard University Press, Harvard.
53. OECD, 2015, *Enabling the Next Production Revolution: Issues Paper*. OECD, Paris, 9 March 2015.
54. Noman, A., Stiglitz, J.E., 2016. *Efficiency, Finance and Varieties of Industrial Policies*, Initiative for Policy Dialogue at Columbia: Challenges in Development and Globalization. Columbia University Press, New York.
55. O'Sullivan, E., Andreoni, A., Lopez-Gomez, C., Gregory, M., 2013. What is new in the new industrial policy? A Manufacturing Systems Perspective. *Oxford Review of Economic Policy*, 29(2), 432-462.
56. Pasinetti, L., 1981. *Structural Change and Economic Dynamics. A Theoretical Essay on the Dynamics of the Wealth of Nations*, Cambridge University Press, Cambridge.
57. Pasinetti, L., 1993. *Structural Economic Dynamics. A Theory of the Economic Consequences of Human Learning*, Cambridge University Press, Cambridge.
58. Penrose, E.T., 1959. *The Theory of the Growth of the Firm*. Oxford, Oxford University Press.
59. Piore, M.J., Sabel, C.F., 1984. *The Second Industrial Divide*. New York, Basic books.
60. Quadrio Curzio, A., 1986. Technological scarcity: an essay on production and structural change. In M., Baranzini, R., Scazzieri, (Eds.), *Foundations of Economics. Structures of Inquiry and Economic Theory*, Basil Blackwell, London and New York, pp. 311-38.
61. Quadrio Curzio, A., Pellizzari, F., 1991, Structural rigidities and dynamic choice of technologies. *Rivista internazionale di scienze economiche e commerciali*, 38(6-7), pp. 481-517.
62. Robinson, J., 1956, *The Accumulation of Capital*, Macmillan, London.
63. Rodrik, D., 2004, *Industrial Policy for the 21st Century*, <http://www.ksg.harvard.edu/rodrik/>
64. Rodrik, D., 2008, *Normalizing Industrial Policy*, Commission on Growth and Development, Working Paper n.3, Washington DC.
65. Scazzieri, R., 1993. *A Theory of Production. Tasks, Processes and Technical Practices*, Oxford, Clarendon Press.

66. Scazzieri, R., 2014. Increasing returns: towards a structural theory. *Structural Change and Economic Dynamics*, 29, 75-88.
67. Schwab, K., 2016. *The Fourth Industrial Revolution*. Geneva, World Economic Forum.
68. Smith, A., 1776. *An Enquiry into the Wealth of Nations*, reprinted in 1960 by J.M. Dent & Sons Ltd., London (two volumes).
69. Womack, J.P., Jones, D.T., Roos, D., 1990. *The Machine that changed the world*, Rawson Associates, New York.