Industrial ecosystems and policy for innovative industrial renewal: A new framework and emerging trends in Europe

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Abstract

Over the past two decades the global industrial landscape has been reshaped by profound structural transformations and the emergence of new forms of "structural dualism", both across and within countries. Major industrialised and emerging economies have reacted to (and, sometimes, proactively triggered) these structural transformations by adopting a wide range of industrial, manufacturing and technology policies. In mature industrial economies, governments have increasingly focused their attention on reverting the worrying trends associated with the increasing deterioration of their industrial ecosystems. Against this background, and with a focus on mature industrial economies, the paper develops a new analytical framework to analyse the *architecture* and *dynamics of modern industrial ecosystems*, and formulate effective *industrial policy for innovative industrial renewal*. By contrasting three cases from Europe – UK, France and Germany – the paper also offers evidence on the emerging approaches in industrial policy making among major European countries.

Keywords:

Industrial ecosystem; emergence and decline; transformation and structural traverses; structural readiness; industrial policy; UK; Germany; France.

1. Introduction

Over the past two decades the global industrial landscape has been reshaped by profound structural transformations and the emergence of new forms of "structural dualism", both across and within countries. The rise of new industrial powers, China in particular, has led to the restructuring of global production systems and the reorganisation of production cycles, as well as changes in global trade patterns. These structural dynamics have been due both to changes within, and to increasing interdependencies across, national manufacturing systems, their constituent sectors, productive firms and technologies. In this respect, the global financial crisis has been accelerating ongoing structural trends, as revealed by the increasing redistribution and polarisation of manufacturing production across countries and regions of the world. The financial crisis has also revealed the risks associated with the financialisation of firms, the short-termism of the financial sector and its detachment from the real economy.

Over this period, and increasingly in the current conjuncture, major industrialised and emerging economies have reacted to (and, sometimes, proactively triggered) these structural transformations by adopting a wide range of industrial, manufacturing and technology policies. Among mature industrial economies, in particular, governments have increasingly focused their attention on reverting the worrying trends associated with manufacturing offshoring and the increasing deterioration of their industrial base, followed by a relocation of knowledge-intensive production services. The resulting structural unemployment and uncertainty has put further pressure on their economies and public finances (Berger, 2013; Andreoni and Gregory, 2013; Tassey, 2007 and 2014; Andreoni and Chang, 2016; Andreoni, 2016; Noman and Stiglitz, 2016).

Against this background, and with a focus on mature industrial economies, the paper develops a new analytical framework to analyse the *architecture* and *dynamics of modern industrial ecosystems*, and formulate effective *industrial policy for innovative industrial renewal*. Industrial ecosystems are complex multi-layered systems (spanning across different economic sectors) whose organisations operate at the 'glo-cal' interface as parts of networks of production, knowledge creation and resource flows. Multiple streams of literature have addressed the complex nature of these systems, their global spread – GVCs (Global Value Chains) and GPNs (Global Production Networks) – and local manifestation – districts, clusters and innovation systems – as well as their internal dynamics beyond traditional sector-focused analyses.

Building on a critical introductory review of this vast literature, the paper outlines a new analytical framework focusing on the relationship between *different types of sectoral value chains* (and their production subsystems or "tiers") and their underpinning *technology platforms* (including their constituting "key technologies"). Any given industrial ecosystem includes organisations operating within one (or multiple) sectoral value chains and relying on a specific combination of resources and capabilities – their technology platforms. Sectoral value chains and technology platforms are therefore the two main structural dimensions of an industrial ecosystem, thus, the two main units of analysis to be considered in disentangling its architecture.

The architecture of industrial ecosystems continuously changes as a result of evolutionary dynamics of emergence, decline and transformation. The *"emergence"* of a new industrial ecosystem in a given location can be triggered by the rise of new entrepreneurial organisations developing existing or emerging technologies – technology push. New entrepreneurial organisations can also emerge in response to market/demand pull dynamics and develop new strategic sectoral value chains and develop/acquire required technologies. At the same time, the competitive pressure impressed by entrepreneurial organisations developing emerging technologies and sectoral value chains may lead to the *"decline"* of existing organisations specialised in mature sectoral value chains, or tasks/product segments. Thus, new industrial ecosystems and their entrepreneurial organisations can emerge, while others can decline.

More often, however, industrial ecosystems undergo processes of *"transformation"* whereby the same existing entrepreneurial organisations move away from mature or declining sectoral value chains (or task/product segments) and/or reconfigure and/or redeploy their resources and capabilities to capture new opportunities. The *"innovative industrial renewal"* of a mature industrial ecosystem is a complex process of transformation involving different types of *"structural traverses".* In response to emerging opportunities, these structural traverses may entail innovative industrial renewal processes across sectoral value chains or across technology platforms.

Industrial ecosystems have a different readiness when it comes to capture emerging opportunities, or responding to a potential decline through innovative industrial renewal. The readiness to change will depend on the two structural dimensions constituting the architecture of the industrial ecosystem, that is, the types of sectoral value chains and technology platforms present in the ecosystem in a certain point in time. The assessment of the *structural readiness* of an industrial ecosystem, that is, its capacity to capture emerging technology and market opportunities as well as its ability to transform along structural traverses becomes a key area of policy intervention in mature industrial economies. Here, industrial policy should focus on nurturing emerging technologies and strategic sectors, but also, and more critically, should target those structural traverses cutting across different sectoral value chains and technology platforms which may trigger innovative industrial renewal dynamics.

By contrasting three cases from Europe – UK, France and Germany – the paper offers evidence on the emerging approaches in industrial policy making among major European countries and the ways in which they have been targeting emerging technology, sectoral value chains and the overall structural readiness of their industrial ecosystems. In view of the proposed analytical framework, the paper concludes by discussing these emerging trends, their strengths and weaknesses, in order to identify the main areas of policy intervention for innovative industrial renewal.

2. Beyond sectors, the 'glocal' production frameworks: a critical review

Modern industrial economies consist of complex and dynamic interdependencies spanning across various industries and sectors. These interdependences unfold in a wide range of technological, organisational and institutional dimensions and involve different types of system actors. These are business organisations both competing and cooperating in multi-tiered and 'glo-cal' production systems, but also various types of public and public-private technology intermediaries and multi-level public policy actors. Within these manufacturing systems, structural economic dynamics are mainly triggered by changes in the technology platforms underpinning industrial sectors and changes in the firms' resource-capabilities. In turn, the adoption of new technologies at full industrial scale often requires organisational reconfigurations involving both the Marshallian 'internal' and 'external' firm.

The way in which economists have traditionally linked changes in technologies with broader industrial dynamics at the level of the economic system has been to adopt sectors or sub-sectors (industries) as main units of analysis. It is not surprising then that almost all industrial data are collected for sectors and industries as if they were the unique level of aggregation of production activities.

However, as stressed by Nathan Rosenberg (1963), sectors are compositional heuristics that very often hide more than reveal the functioning of industrial ecosystems.

> "it is necessary to discard the familiar Marshallian approach, involving as it does the definition of an industry as a collection of firms producing a homogenous product- or at least products involving some sufficiently high cross-elasticity of demand. For many analytical purposes it is necessary to group firms together on the basis of some features of the commodity as a final product; but *we cannot properly appraise important aspects of technological developments in the nineteenth century until we give up the Marshallian concept of an industry as the focal point of our attention and analysis.* These developments [rapid technical change in the American production of machine tools] may be understood more effectively in terms of certain functional processes which cut entirely across industrial lines in the Marshallian sense…" (Rosenberg 1963:422; italics added).

Today the adoption of the "industrial sector" - the most traditional unit of analysis for which data are available - is becoming even more inadequate for understanding twenty-first century glocal production. This is due to multiple reasons, including

(i) the increasing vertical disintegration of industrial sectors and the related modularisation of production processes;
(ii) the blurring of sectoral boundaries, especially as a result of the outsourcing of knowledge intensive production-related services;
(iii) the emergence of regional/global value chains and system integrators orchestrating complex supply chains and production cycles of increasing scale and speed;
(iv) the diversification and specialisation of firms in very different and technology-specific product-segments (both intermediate and final products) within the same sectors;
(v) the increasing complexity of products, and their becoming "product systems" integrating multiple components, technologies and even services;
(vi) the increasing complexity of technology platforms (and constituting enabling technologies) underpinning multiple sectors.

In recognition of these issues, over the last three decades, economists have adopted a number of alternative heuristics to unpack "glo-cal production systems", namely the concepts of global value chains-global production networks and the one of districts-clusters-ecosystems. In particular, the concept of "global value chain" has been increasingly adopted to analyse the governance and distribution of production functions (or tasks) among different networked-production units located in different countries (multi-tiers organisational structure).

Within this framework, the value creation and capture dynamics have acquired central stage (Milberg and Winkler, 2013; Gereffi, 2013). In particular, a number of scholars have analysed the implications of this new global "mode of production" for value creation, capture and distribution among different countries, especially those experiencing dramatic processes of offshoring and increasing de-industrialisation (e.g. Andreoni and Gregory, 2013; Andreoni and Chang, 2016b; Chang and Andreoni, 2016; see Amador and Cabral, 2014 for a comprehensive survey).

These studies tend to go beyond the "sector" as main unit of analysis, which is replaced by the one of "task" and "chain/network". A production task is linked to a certain functional stage of the production process or the production of a finite intermediate product component. The network is multi-country (often more regionally confined than truly global) and composed by multiple productive organisations involved in different stages and potentially operating in multiple sectors.

The GVC framework stresses the opportunities for companies (and the local production systems) to specialise in specific production tasks or components, preferably "high-value niches", while avoiding the building up of entire vertically integrated industrial sectors or blocks of industries. The idea of a selective form of specialisation in tasks, driven by capturing value opportunities, would encourage companies to focus on activities such as R&D, design and downstream post-sale services, while dismissing more "traditional" (at least perceived so) manufacturing processes.

Although this literature has revealed important aspects of modern manufacturing, it also presented a number of limitations. Two of them are critical for the development of our theoretical framework, while more issues have been raised in other contributions (Chang and Andreoni, 2016; Andreoni 2017).

First, in order to capture "high value niche" opportunities along the value chain via tasks specialisation, companies often have to require multiple sets of complementary production capabilities cutting across multiple stages of the value chain and different technology domains (Figure 1). This is increasingly so in the case of complex high-tech high-value products or components. For example, the task specialisation in design often requires the direct access in the same local industrial ecosystems of specific production capabilities for prototyping and manufacturing to scale-up of products and processes. This means that task specialisation requires the identification of complementary sets of capabilities which constitute the technology platform underpinning the task or set of related tasks.

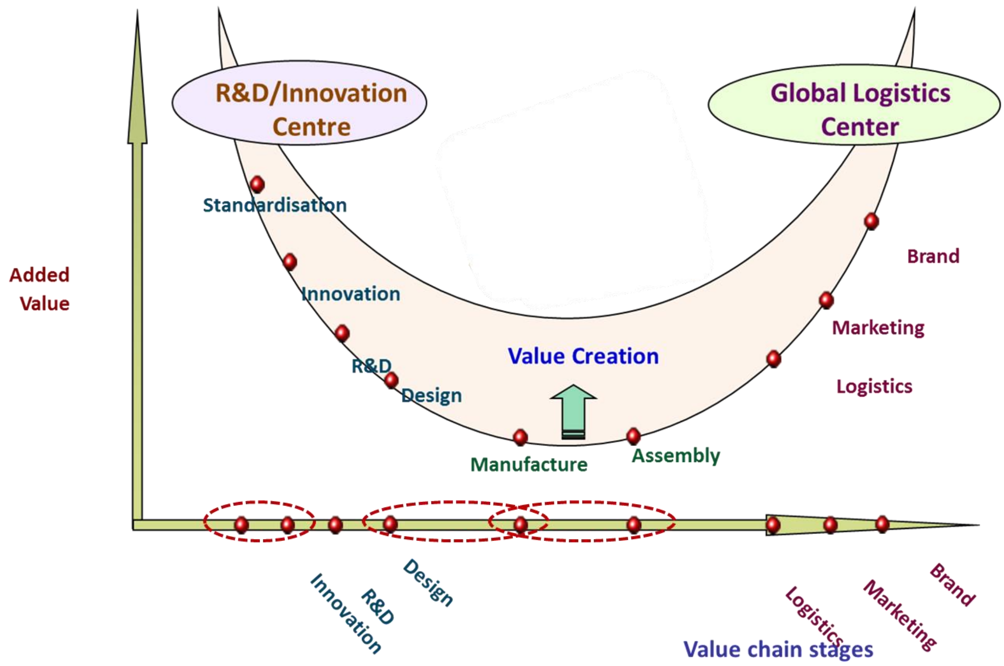

Figure 1: Capturing high value niches and the need for multiple sets of complementary capabilities

Source: Adapted from Shih, 2005

Traditionally, these sets of capabilities where developed within vertically integrated firms (Penrose 1959), or within industrial blocks. Dahmen's concept of a development block is a structural heuristic for capturing various forms of complementarities linking a set of innovative production activities (or specific tasks) across and within manufacturing systems and countries.

According to Dahmen (1989:132) the development block "refers to a sequence of complementarities which by way of a series of structural tensions, i.e., disequilibria, may result in a balanced situation". The emergence of development blocks may be either the result of ex-post 'gap filling', whereby a "structural tension" or bottleneck is solved, or the result of an ex-ante 'creation of markets' by coordinated entrepreneurial activities or 'economic planning' by government institutions. As documented in the history of the steel industry (Dahmen 1989) or in empirical analysis of other Swedish industries (Enflo et al. 2007 adopt cointegration analysis), development blocks trigger cumulative dynamics of regional differentiation in technological and other factor endowments.

In sum, the possibility for firms in a certain location to develop a competitive advantage in a certain task/stage and, thus, capturing a "high value niche", will depend on complementary set of different capabilities whose development might require the involvement in more than one stage of the same (or other) value chains. In successful industrial ecosystems, like the Boston route (Best, 1990 and 2013) and the Emilia Romagna region (Andreoni and O'Sullivan, 2014; Andreoni et al, 2016; Andreoni and Cantamessa, 2017), these complementary capabilities have developed along different cycles of industrial transformation and renewal of vertically integrated firms backed up by a dense network of local specialised suppliers and contractors.

The second problem in the GVC approach is that it has increasingly become a-sectorial, that is, it has led to undermining a number of specificities of industrial sectors (or groups of industrial sectors). Given the structural heterogeneity characterising industries, in particular manufacturing sectors (Andreoni and Chang, 2016), we can expect that the value creation and capture opportunities are in fact distributed in different ways across value chains in different sectors. This is why the complete abandonment of the sectoral heuristic might be problematic. In other terms while vertically integrated sectors are poor heuristics to understand the modern network/value chain mode of production, still these networks and value chains are fundamentally heterogeneous and present specific features in terms of their modularity, their length and distribution across countries, and the underpinning set of technological capabilities.

The value chain "shape" and "length" depends on multiple factors, including specific sectoral and organisational features, as well as the combination of complementary capabilities – i.e. technology platform – required to execute tasks in the different stages of the chain, and these tasks tend to be different across sectors. For example, aerospace and medical device sectors are both characterised by complex technology platforms as they both produce multi-thousands “critical system products”.

Some of these technological and organisational specificities, and in particular the location-specific nature of these technologies and sectoral value chains, have been at the centre of the research on districts, cluster and innovation systems since the 1980s. The literature on industrial districts focuses on one specific form of industrial organisation characterised by geographical agglomerations of small firms embedded in a certain socio-cultural context (Becattini, 1989). The distinctive flexible production system and development model of the Third Italy was one the main international laboratories for the analysis of the industrial district phenomenon (Brusco, 1982; Piore and Sabel, 1984; Best, 1990; Andreoni et al., 2016).

Over the years, research on industrial districts has increasingly overlapped with the rapidly growing literature on clusters. Despite substantial differences these terms have been used interchangeably by some researchers. Although widely adopted, the concept of cluster remains surprisingly underdeveloped and it is often used in contradictory forms (Asheim et al., 2006; Lin, et al. 2006; Kajikawa, 2010; Pitelis, 2012), especially when it comes to the following three issues:

(i) the definition of its industrial and geographical boundaries;
(ii) the characterisation of the different actors involved in the process of value creation and their underpinning distinctive competencies;
(iii) the detection of technological complementarities and linkages through which entrepreneurial opportunities are co-produced

A similar set of challenges have been faced by those strands of literature focusing on innovation and technological dynamics within different geographical and sectoral boundaries. The innovation system perspective has provided frameworks for understanding different actors’ involvement in the creation and capture of innovation opportunities (Dosi et al, 1988), as well as their distinctive functions (Makdard and Truffer, 2008; Hekkert et al. 2007). Other scholars have developed these perspectives focusing on different levels of aggregation (local, regional and national) or adopting sectoral systems as main units of analysis (Breschi and Malerba, 1997).

More recently, the ‘ecosystem’ construct is emerging as a flexible framework fruitfully integrating complementary research strands in value creation and technological interdependence (Adner and Kapoor, 2010); global production networks, processes of modularisation driven by different product architectures (Sturgeon 2002; Brusoni and Prencipe, 2011); and technologically-focused investigations of entrepreneurial activities within networks (Garnsey and Leong, 2008).

3. The Architecture of Industrial Ecosystems

The first conceptualisation of the "manufacturing system" as a main unit of analysis of the productive economy was done by Charles Babbage (1832) *On the Economy of Machines and Manufactures.* In the *Wealth of Nations* Adam Smith (1776) had already introduced the notion of "division of labour", whose manifestation in the "putting-out" system anticipated the current notion of supply chain. However, Babbage was the first one to identify the analytical problems associated with studying a manufacturing *system* and, more critically, its internal hierarchical structure and the related laws of decomposability in *sub-systems*. Indeed, the possibility of increasing and decreasing scale of production units is determined by a proportionality law (Law of Multiples) which determines – structurally – the emergence of sub-systems within the overall manufacturing system (Andreoni and Scazzieri, 2013; Andreoni, 2014). According to this law maintaining any given level of productive efficiency presupposes increasing process scale by integer multiples of the minimum scale allowing that level of efficiency. Scale-related structural constraints set the motion of transformation of firms, and unlock productive opportunities.

This complex system approach of classical economists was later advanced in the seminal work of Alfred Marshall and Nicholas Georgescu-Roegen on 'bioeconomics', Herbert Simon on "The Architecture of Complexity" (1962), George Richardson (1972) on the 'organisation of industry', and Brian Arthur on the nature of technology and systems (1989; 2014). More recently, various contributions have addressed the increasingly complex interdependencies within industrial agglomeration and value networks (see the collection of seminal papers in Adner et al. 2013; also Best, 1990 and 2013; Garnsey, 1998; Garnsey and McGlade, 2006).

Drawing from the complex system theory, the industrial ecosystem perspective has pointed to the importance of analysing interdependent innovations involving different firms, each of them performing different functions along the value chain (Adner and Kapoor, 2010; Best, 2013; Andreoni, 2014; Andreoni et al. 2016). Thus the structure of interdependences linking system integrators and their suppliers (upstream) and complementors (downstream) acquires a central role in explaining value creation and value capture dynamics. Given its open system nature, the concept of innovation and industrial ecosystems allows going beyond sectoral and narrow geographical boundaries. It is also highly compatible with those approaches detecting particular actors in the ecosystem (Probert et al., 2013; Andreoni and O'Sullivan, 2014) as well as specific innovation system functions and different technology types (and relative functions) underpinning value chains.

The effectiveness of today's industrial policy making is fundamentally constrained by the difficulties that economists face in disentangling the architecture of industrial ecosystems and the multiple set of interdependencies involved. The analysis of these ecosystems calls for a continuous updating of our heuristics and metrics and the consideration of the relevant production units and levels of aggregation (Andreoni and Scazzieri, 2013).

Building on some of the above mentioned contributions and heuristics in complexity theory, we propose to look at the architecture of industrial ecosystem starting from two main units of analysis, namely different types of

(i) sectoral value chains (and their constituting tiers or sub-systems)
(ii) technology platforms (and their constituting types of technologies).

The first unit of analysis – *sectoral value chain types* – is related to the decomposition of the overall industrial ecosystem in productive sub-systems. Within each industrial ecosystem, there are a number of sectoral supply chains around which the productive activities of the overall economy are structured (both manufacturing and service industries). The following five are the main *"types"* of sectoral supply chains. Each of them focuses on different types of activities:

1. the production of final consumption goods (and the related assembly of components)
2. the production of components (intermediate goods)
3. the production of the production technologies
4. the provision of production-related services
5. the production of raw industrial materials

Each one of these sectoral value chains is based on different technology platforms integrating various types of technologies and technology systems (see Figure 2). As eloquently documented in Tassey (2010:6): "Most modern technologies are systems, which means interdependencies exist among a set of industries that contribute advanced materials, various components, subsystems, manufacturing systems and eventually service systems based on sets of manufactured hardware and software. The modern global economy is therefore constructed around supply chains, whose tiers (industries) interact in complex ways". This means that some of these technology platforms underpin production processes of closely-related industrial sectors as well as different product-value segments within the same industrial sector. Technologies are thus linked by a set of dynamic interlocking relationships spanning across sectors and value-product segments

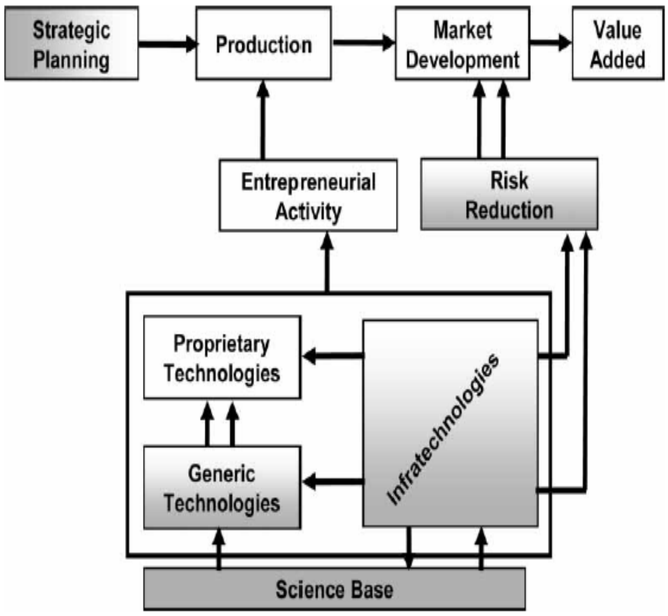

Figure 2: Tassey's classification of technology types

Source: Tassey, 2007

The emergence of these dynamic interdependencies as well as the technology transition from one type of technology platform to another tends to follow cyclical patterns. Often these technology transitions open new value-product segments opportunities for business organisations. The existence of technology cycles is particularly evident in relation to technology transitions underpinning firms' shifts from mature product segments to higher value-product segments within the same industrial sector (Andreoni et al, 2016).

The second unit of analysis we propose to disentangle the architecture of industrial ecosystems is therefore the technology platforms underpinning the sectoral value chains. Each technology platform is composed by one or more "key" technology systems. Their identification and selection can follow different criteria associated with different technology properties:

i) their being "transversal", that is, the extent to which they are deployed in multiple sectoral supply chains
ii) their degree of "embeddedness", that is, the extent to which they play a critical role within integrated technology systems
iii) their "quality enhancing potential", that is, the extent to which they allow increasing quality products and their functionalities
iv) their "productivity enhancing potential", that is, the extent to which they affect production processes productivity
v) their being "strategic" in terms of facing major social and economic future challenges or markets

In the economic literature, technologies and technology systems responding to a number of these properties (especially the transversal one) have been associated with the concept of General Purpose Technologies (GPTs). GPTs have been studied especially with reference to the emergence of new technology paradigms and their broader impact on the economy (for a review see Jovanovic and Rousseau, 2005; Bresnahan, 2010).

Starting from 2010, the EU technology and industrial policy have identified and focused its interventions on a set of key technologies and technology systems characterised by more than one of the properties highlighted above. These are:

- Advanced Materials (AM)
- Advanced Manufacturing Systems (AMS)
- Industrial Biotechnology (IB)
- Photonics (PH)
- Micro and Nano Electronics (MNE)
- Nanotechnology (NT)

Given their transversal nature, high potential and strategic role, these technologies have been called Key Enabling Technologies (KETs).

"KETs are knowledge and capital-intensive technologies associated with high research and development (R&D) intensity, rapid and integrated innovation cycles, high capital expenditure and highly-skilled employment. Their influence is pervasive, enabling process, product and service innovation throughout the economy. They are of systemic relevance, multidisciplinary and trans-sectorial, cutting across many technology areas with a trend towards convergence, technology integration and the potential to induce structural change"

KETs are technologies/technology systems underpinning the development of today's most complex products – in particular smart devices able to interact with the users, collecting and using data (Internet of Things, IoT) and performing multiple services. KETs are also central in different technology platforms underpinning supply chains of different types. Thus, they are deployed transversally within the industrial ecosystem, and across the different types of sectoral supply chains listed above.

Similar technology mapping analyses have been conducted in the US - as part of the PCAST Reports to the President focusing on the National Manufacturing Strategy - and in the UK, for the UK Future of Manufacturing study of the Government Office for Science. In the US, 'Advanced manufacturing' is expected to increasingly dictate the characteristics of future products, as well as the production methods used in the future. The President's Council of Advisors on Science and Technology in the United States defines Advanced Manufacturing as "a family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies.”

In the UK’s Future of Manufacturing report, a number of pervasive and secondary technologies for future manufacturing activities were also identified. The pervasive technologies which are likely to have a broad future impact on manufacturing systems include information and communications technology (ICT), sensors, advanced and functional materials, biotechnologies and green technologies. Among the secondary technologies the report identifies the following: big data and knowledge based automation, internet of things, advanced and autonomous robotics, additive manufacturing (also known as 3D printing), cloud computing and mobile internet.
As the above technology priorities suggest, it is possible to adopt multiple criteria to identify the key technologies/technology systems, as well as their components and sub-systems (Kamp, 2012). The selection and decomposition of the complexity associated with each of them, may be determined by the specific analytical and policy design needs, or the result of a narrowing down of the analysis by regional industrial ecosystems and their key technologies (see Andreoni and Cantamessa, 2017 for a discussion of the Emilia Romagna and Piedmont cases).

To summarise, the architecture of an industrial ecosystem – be it national or regional – is thus composed by sectoral supply chains (SSCs) and underpinning key technologies organised around platforms. A matrix is introduced here to visualise the two structural dimensions of an industrial ecosystem (Figure 3). This framework also helps in analysing the multiple set of interdependencies and dynamics characterising an industrial ecosystem, especially those between sectoral supply chains and underpinning technologies.

Industrial ecosystem architecture	Industrial ecosystem supply chains Types of Sectoral supply chains				
Key Technologies / Technology platforms	SSC1 Final products / goods	SSC2 Components & sub-systems	SSC3 Industrial Materials	SSC4 Production Technologies	SSC5 Producer Services
Advanced Materials (AM)					
Industrial Biotechnology (IB)					
Photonics (PH)					
Micro & Nano Electronics (MNE)					
Nanotechnology (NT)					
Advanced Manufacturing Systems (AMS)					

Figure 3: The architecture of industrial ecosystems

Source: Author

4. The Dynamics and Structural Readiness of Industrial Ecosystems

Industrial ecosystem dynamics result from evolutionary processes of emergence, decline and transformation.

The *"emergence"* of a new industrial ecosystem in a given location can be triggered by the rise of new entrepreneurial organisations developing existing or emerging technologies (technology push). Emerging technologies, in particular, tend to have a disruptive impact on the existing technology platform, and require organisations to develop new sectoral value chains capable of producing and/or deploying and/or commercialising them for the market. New entrepreneurial organisations can also emerge in response to market/demand pull dynamics and develop new sectoral value chains and develop/acquire the required technologies. Industrial policy in mature industrial economies has usually targeted the emergence of new industrial ecosystems by prioritising research in emerging technologies, or emerging sectors and related markets.

The competitive pressure impressed by entrepreneurial organisations developing emerging technologies and sectoral value chains may lead to the *"decline"* of existing organisations specialised in mature sectoral value chains, or tasks/product segments. These organisations can operate in the same or other locations and markets. Industrial ecosystems affected by a generalised decline of their existing entrepreneurial organisations, or where emergence dynamics are weak, can gradually disappear. The decline of an industrial ecosystem results from the inability of its organisations to either respond to the mounting competitive pressures or capture new technology and market opportunities. For example, entrepreneurial organisations may be unable to re-organise their sectoral supply chain or develop/acquire the emerging technologies.

More often, however, industrial ecosystems undergo processes of *"transformation"* whereby existing entrepreneurial organisations move away from mature or declining sectoral value chains (or task/product segments). In doing so these organisations can transform the industrial ecosystem by changing both its sectoral value chains and underpinning technology platforms. However, the transformation of the industrial ecosystem is not an automatic process and many of the existing entrepreneurial organisations can decline along the way.

The *"innovative industrial renewal"* of a mature industrial ecosystem is a complex process of transformation, beyond the simple dynamics of emergence and decline described above (Pensore, 1959; Richardson, 1972; Best, 1990 and 2013; Andreoni and O'Sullivan, 2014; Doussard and Schrock, 2015; Andreoni et al. 2016). Innovative industrial renewal dynamics are led by existing entrepreneurial organisations able to diversify their production by

(i) Shifting towards closely complementary sectoral value chains
(ii) Re-configuring and re-deploying their resources and capabilities towards the creation of new technology platforms.

In the former case, entrepreneurial organisations can diversify their activities towards higher value-added task/product segments and markets; in the latter, they can recombine their resources and capabilities or integrate them with emerging technologies towards new applications.

As a result of these two types of what we call here *"structural traverses"*, an industrial ecosystem can change and diversify towards its innovative industrial renewal. Those industrial ecosystems where these two innovative industrial renewal dynamics go hand in hand (and are linked) with the emergence dynamics described above, are characterised by strong innovation and competitiveness performances.

The analytical framework introduced above offers a new heuristic to disentangle the innovative industrial renewal dynamics across sectoral value chains and technologies within industrial ecosystem (Figure 4). By interfacing the meso-level sectoral supply chain dimension and the underpinning micro-level key technologies and platforms, we are now able to identify two sets of innovation dynamics arising from interdependencies across different "types" of sectoral supply chains and different technologies and platforms. These interdependencies are different from traditional input-output relationships among sectors of the economy, as they are inherently associated with micro-structural changes in technologies and the emergence/discovery of technological linkages along different relatedness and diversification trajectories. In fact, the degree of relatedness among sectors can be defined in terms of their dependence on a similar set of underpinning technologies/technology systems (and the related capabilities).

With the increasing transformation in the global manufacturing landscape, these structural traverses leading to cross-sectoral and cross-technology innovation dynamics have acquired increasing importance. Traditionally, industrial ecosystems structured around vertically integrated sectors would mainly experience internal processes of structural learning (Andreoni, 2014) whereby a new technical solution emerged in one sector would be increasingly adopted by firms to transform their business in the same sector.

In modern industrial ecosystems characterised by the presence of multiple sectoral supply chains involving multiple actors (at different levels/tiers) located in various locations, the emergence of an innovative technical solution can lead to structural traverses across sectoral value chains and, thus, the emergence of new products or the transformation of processes which were ex ante apparently unrelated.

For example, advanced materials (e.g. membranes, polymers for micro-tubing) developed in the design and manufacturing of medical devices can be adopted to increase the performance of components and technology systems in the automotive sector. The production of the same advanced materials might also require fundamental innovations in the production technologies supply chains (e.g. co-injection technologies for micro tubing), and a set of infratechnologies required to test and validate the new products or production technologies. These new production technologies, in turn, can lead to an advancement/bottleneck removal in the production technologies underpinning *other* sectoral supply chains (Andreoni and O'Sullivan, 2014).

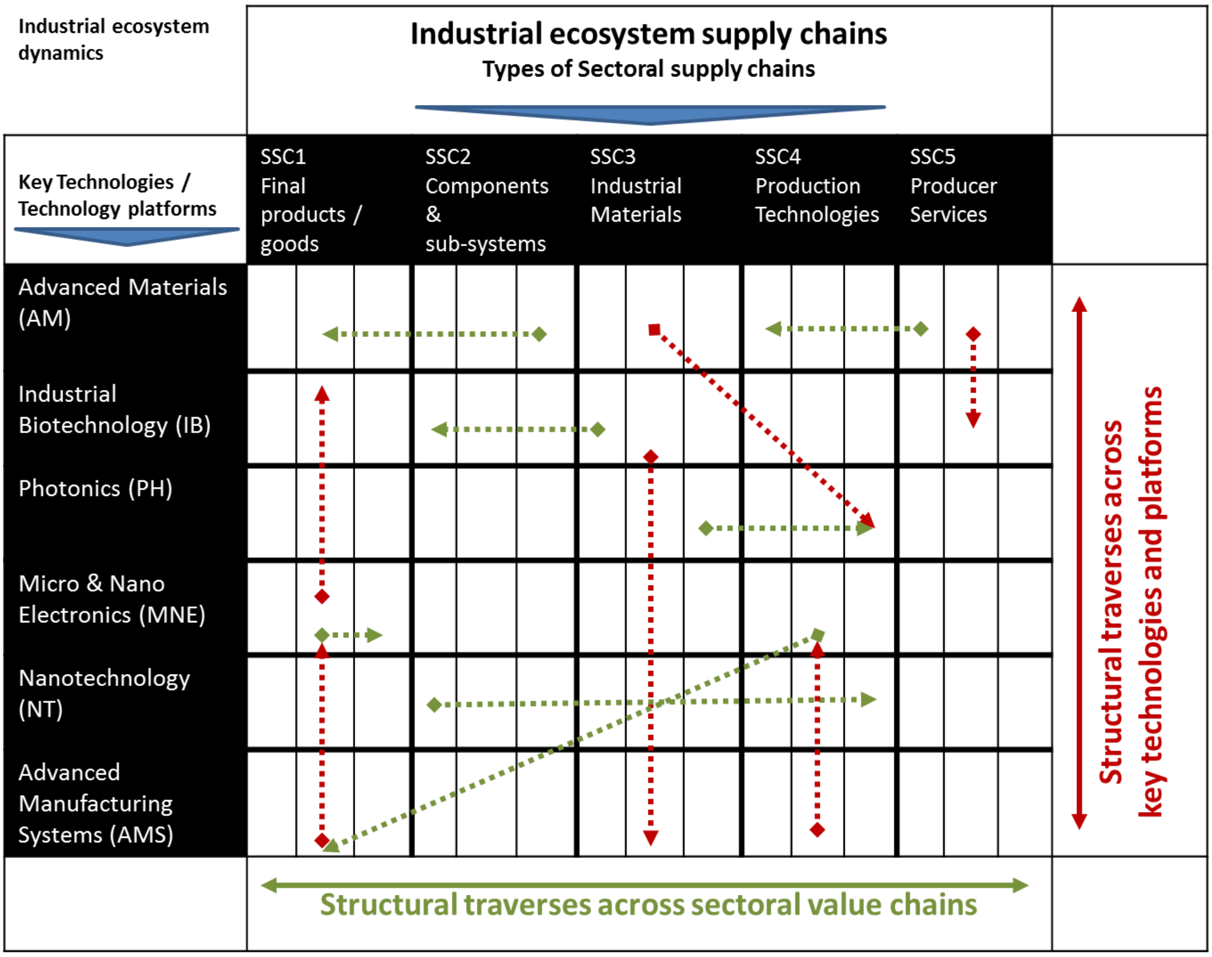

Figure 4: Structural traverses in industrial ecosystems

Source: Author

Those industrial ecosystems such as the Boston route (Best, 1990 and 2013) or the Emilia Romagna region (Andreoni and O'Sullivan, 2014; Andreoni et al, 2016), which have managed to develop and retain over the years a high-value and technologically dynamic manufacturing system have experienced innovative industrial emergence but also, and more critically, processes of innovative industrial renewal along the structural traverses described above. For example (see Andreoni et al., 2016), the packaging machinery value chain in Emilia Romagna was transformed by the increasing adoption of integrated technology platforms – mechatronic systems – which allowed the sectoral value chain to increase the speed of operations, the possibility of collecting data (Internet of Things, IoT) as required in specific high-value segments of the industry. This is a case where industrial renewal was triggered by the integration of different key technologies towards a new technology platform.

As a result of these cross-sectoral and cross-technology innovation dynamics – structural traverses – new interdependent relationships develop among sectoral supply chains which were not connected. Similarly new forms of technology integration and technology integrated systems (also called in the KETs literature multi-KETs) develop along unexpected traverses.

The readiness of an industrial ecosystem to benefit from the emergence and structural traverse dynamics described above depends on three main factors.

First the *technological readiness level* (TRL) of the various key technology/technology systems, especially in terms of their level of development (TRLs) in the specific industrial ecosystem. The TRL is a metric originally adopted in the aerospace industry in the US in the 1980s. Over the last decade it has been increasingly adopted in multiple technology policy and road mapping exercises in the EU context. The following table provides details about the research, development and commercialisation activities associated with different Technological Readiness Levels.

1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be

	tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8. Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

Table 1: Technological readiness levels (TRLs)

Source: US Department of Defence

Second, the *sectoral supply chain readiness* is the result of a number of specific features related to the organisation of the industrial ecosystems, such as the presence of (i) diffused manufacturing capabilities among multiple entrepreneurial drivers; (ii) a supportive technology infrastructure offering the required set of infratechnologies for scaling up technologies/product/processes; (iii) the presence of a financial infrastructure able to fill in the financing gap characterising certain highly risky TRL.

Firms involved in technological development undertake different research, development and manufacturing piloting (R&D&M) activities, each of them entailing different types of financial needs and different levels of risks. Alongside the technological innovation chain (from basic research to mature technology development), then, firms will have to interact with the most appropriate financial institutions within the financial system (Andreoni, 2017b). These institutions often include both public and private actors. The technology development risk is determined both by the specific characteristics of the technology the firms is developing, but also by the existence of a technology infrastructure supporting its development and de-risking the overall innovation chain (Tassey, 2007; Andreoni, 2016). The following schematic provides a framework for evaluating the structural readiness example for the UK and the US industrial ecosystems.

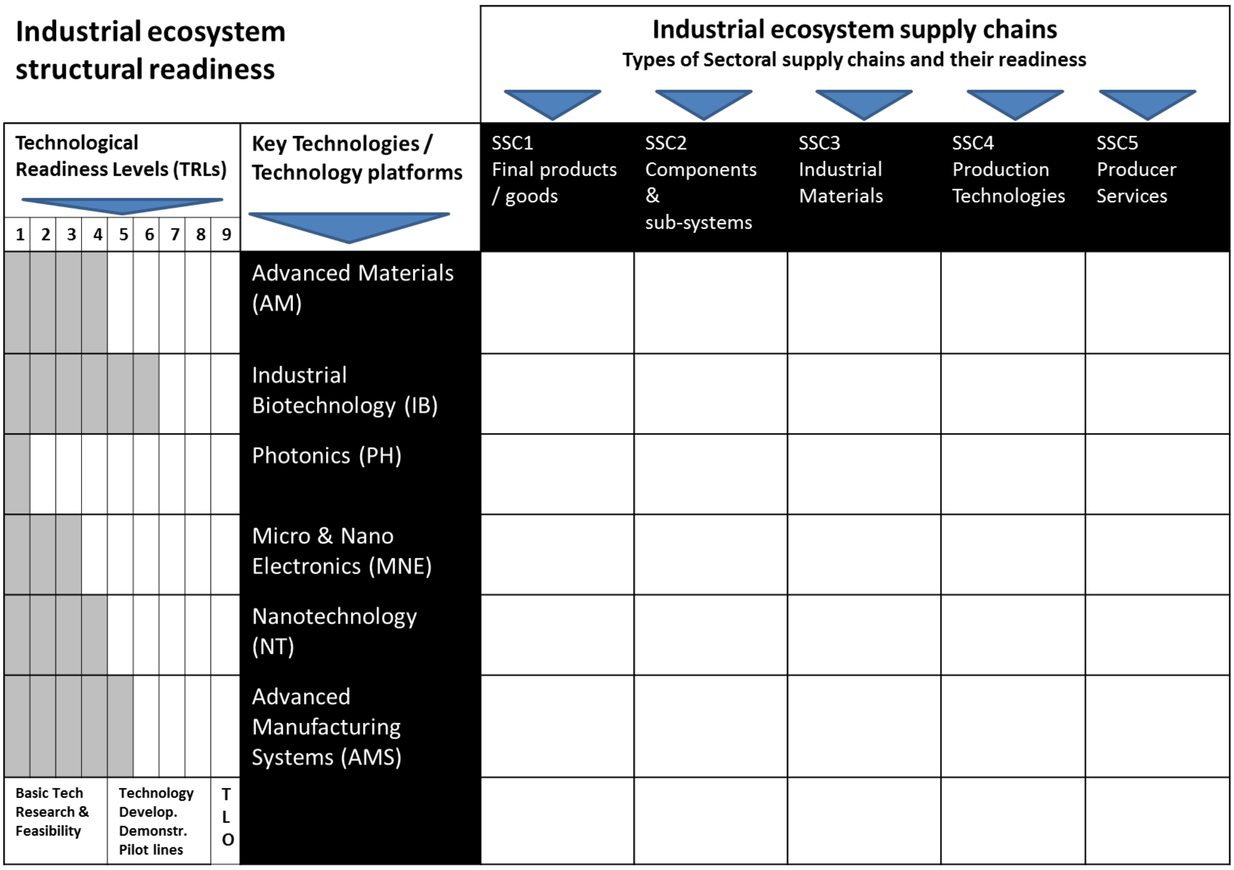

Figure 5: The structural readiness of an industrial ecosystem

Source: Author

The reason why policy makers' assessment of the structural readiness of an industrial ecosystem cannot be limited to the TRLs (as often done at the level of the EU) is that the TRLs only provides an idea of the potential readiness. , The effective structural readiness of the industrial ecosystem comes from the interdependent readiness of the technology/technology systems to commercialisation, and the readiness of the sectoral supply chains in the industrial ecosystem to capture the technological opportunity and translate it in industrial and commercial innovations. The structural readiness framework (Figure 5) also points out how interdependencies matter. If the development of a new product in a certain sectoral supply chain in the industrial ecosystem requires the integration of more than one of the key enabling technologies (multi-KETs), then the readiness in one technology might/not be coupled with others. As a result, an industrial ecosystem lacking a coordinated effort towards increased technological readiness in closely complementary technologies might be unable to create and capture value given the existence of systemic bottlenecks in its technology system.

5. Industrial ecosystem policies for innovative industrial renewal

Governments everywhere are increasingly seeking new sources of growth and wealth creation through policy measures encouraging the development and adoption of emerging technologies, and investments in strategic sectoral value chains of the economy. In fact, there is significant evidence that over the last five years governments have provided additional incentives and support to "strategically targeted" emerging technologies and sectoral value chains, above and beyond more general incentives.

The effectiveness of these industrial policy measures increasingly depends on the capacity of governments to deal with the emerging complexities in industrial ecosystems, as well as their constituting sub-systems and interdependencies, as highlighted in sections 3 and 4. The new analytical framework introduced here has shown how to design effective industrial policy. Governments should:

(i) analyse the architecture of the industrial ecosystem
(ii) target innovative industrial renewal dynamics by identifying potential structural traverses along the technology or sectoral value chain axes
(iii) target the overall structural readiness of the industrial ecosystem

The following three country cases – UK, France and Germany – provide evidence of the different ways in which countries have attempted to support industrial ecosystem dynamics of emergence and innovative industrial renewal. While all of them have targeted both the sectoral value chains and the technology (in particular emerging technologies) axes, each country have given more emphasis to one or the other. The German case finally highlights the possibility of a more integrated industrial policy approach focusing on the overall structural readiness of the industrial ecosystem. For an extended analysis of these country cases see also (Andreoni, 2017).

5.1. Targeting key (emerging) technologies: the case of UK

Over the last decade, the UK Government has become increasingly concerned about the risks associated with over-specialisation in financial services, but also the weak productivity growth of the UK economy, the low levels of business investments and the decline in public R&D since 2008. The financial crisis made clear that 'a more diversified economy is less vulnerable to sector specific shocks' (BIS, 2012:12) and that the UK could have lost important strategic parts of key high tech companies such as Rolls Royce, Pfizer and AstraZeneca. In 2012 the emerging view that the economy needed to be rebalanced and that a long term 'compelling vision' encapsulated in a new industrial strategy led to the formulation of a new "Industrial Strategy".

The 2012 "Industrial Strategy" launched by the *Department for Business, Innovation and Skills (BIS)* marked an important change in the industrial policy approach in the UK, although traces of this emerging new approach can be found also in 2011, when the Regional Development Agencies (RDAs) were substituted by Local Economic Partnerships (LEPs) and new technology centres (Catapults) began to operate. The Industrial Strategy launched in 2012 is a long-term, whole-of-government approach to support economic growth, organised around sectoral industrial strategies and a number of cross-cutting policy areas for intervention including: access to finance; partnerships with sectors; support for emerging technologies; creating a pipeline of skilled workers; government procurement and the development of supply chains.

Building upon the 2012 Industrial Strategy, as well as the influential "Eight Great Technologies" and "The Future of Manufacturing" Reports both released in 2013, in 2014 the UK Government launched a new national innovation plan "Our plan for growth: science and innovation" followed in 2015 by the Treasury Productivity Plan called "Fixing the foundations: Creating a more prosperous nations". The Plan for Growth is an holistic strategy prioritising a number of policy areas, including: 'Nurturing scientific talent'; 'Investing in our scientific infrastructure'; 'Supporting research'; 'Catalysing innovation'; 'Participating in global science and innovation'. As part of this plan and under the renamed innovation agency *Innovate UK* (formerly called Technology Strategy Board, TBS), the UK developed specific policies targeting strategic technologies underpinning key industries, including the "Emerging Technologies and Industries Strategy 2014-2018" and the "Digital Economy Strategy 2015-2018".

The UK government identified eight great technologies in which the UK has business and scientific capabilities and which can offer significant opportunities for the economy. Specifically, each of these great technologies has very high potential for global markets and long-term benefits for society. Moreover they enable wide-ranging application across industries and sectors towards the creation and delivery of new products and services. In 2012 the UK government committed an additional £600 million investment in these great technologies whose development was considered critical to address future 'grand challenges', including developing cost effective low carbon power sources and storage solutions for energy-hungry economies; harnessing and managing scarce resources; improving human, animal and plant health.

The Eight Great Technologies identified were:

a) Big data and energy-efficient computing: The UK aims to be in the vanguard of the big data revolution and energy-efficient computing which will transform scientific inquiry and many industries.
b) Satellites and commercial applications of space: There is a surge in data coming from satellites which do not just transmit data but collect data by earth observation. The UK aims at becoming a world leader in satellites and especially in analysing the data from them.
c) Robotics and autonomous systems: There are particular challenges in collecting data from a range of sources in designing robots and other autonomous systems. This was seen by the UK as a general purpose technology with applications ranging from assisted living for disabled people through to nuclear decommissioning.
d) Synthetic biology: Modern genetics has emerged in parallel with the IT revolution and there is a direct link – genetic data comes in digital form. The future is the convergence of "dry" IT and "wet" biological sciences and the UK wants to be a leader in this.
e) Regenerative medicine will open up new medical techniques for repairing and replacing damaged human tissue.
f) Agri-science: Although genetics is above all associated with human health, advances in agricultural technologies can put the UK at the forefront of the next green revolution.
g) Advanced materials and nano-technology: The possibility of designing new advanced materials from first principles will enable technological advances in sectors from aerospace to construction. Quantum photonics is an exciting area where advanced materials and digital IT converge.
h) Energy and its storage: One of the most important applications of advanced materials is in energy storage. This and other technologies will enable the UK to gain from the global transition to new energy sources.

In 2014, the Growth Plan proposed further actions and expanded the list of targeted technologies, including graphene and quantum technologies. In Graphene technologies the UK has invested more than £90 million across the country to support existing research and create new infrastructure including three new graphene centres and two Centres for Doctoral Training. As for Quantum technologies, the UK has invested £270 million to develop a national network of research hubs that will provide postgraduate skills, research and infrastructure, including a £50 million innovation programme to support business-led feasibility and demonstrator projects.

UNITED KINGDOM		
Criteria	**Strategic Targets**	**Instruments**
Boosting markets	Aerospace, Automotive, Life Sciences, International Education, Professional and Business Services Advanced materials and nano-technology	• Patent box (to be closed) • R&D Tax credits • Catapults (ATI) • Higher Apprenticeship Schemes
Fixing markets	Agricultural technologies, Information economy, Construction (especially infrastructures), Oil and Gas, Nuclear. Advanced materials and nano-technology	• Patent box (to be closed) • R&D Tax credits • Business Bank • Catapults • Higher Apprenticeship Schemes • Small Business Research Initiative (SBRI)
Creating markets	Big data and energy-efficient computing Satellites and commercial applications of space Robotics and autonomous systems Synthetic biology Graphene Quantum technologies	• Patent box (to be closed) • R&D Tax credits • Small Business Research Initiative (SBRI) • Catapults • Knowledge Transfer Network • Innovate UK Research Funds
Sustaining markets	Offshore wind Robotics and autonomous systems Regenerative medicine Agri-science Energy and its storage	• Patent box (to be closed) • R&D Tax credits • Small Business Research Initiative (SBRI) • Catapults • Knowledge Transfer Network • Innovate UK Research Funds

Table 2: Targeting key (emerging) technologies: the case of UK

Source: Author; see also Andreoni, 2017

The selection of the above emerging technologies was inspired by the following criteria:

- Boosting and Fixing markets: Investments in early-stage technologies present multiple market and coordination failures which the strategies attempt to address
- Creating markets: The emerging technologies tend to have high commercial and global market potential. In order to capture these opportunities, the strategies address the capability of the UK research and industrial system to scale up and diffuse these technologies towards the creation of new markets.
- Sustaining markets: The emerging technologies provide support for all sectors of the economy and a broad set of social and environmental challenges.

5.2. Targeting sectoral value chains: the case of France

France's economic performance in recent decades has been relatively modest. While productivity growth has been relatively good, France is lagging in terms of R&D carried out by businesses, and by SMEs in particular. Businesses in France spend less on R&D (1.5% of GDP) than their counterparts in Germany (2% of GDP) and other leading countries. The difference can be explained partly by France’s sectoral structure, particularly the small size of its manufacturing sector (OECD Review of Innovation Policy, France 2014).

The links between private and public research are also weak (*France: restoring competitiveness*, OECD, 2013). Furthermore, innovative entrepreneurship is fragile: France is below the OECD median for patents filed by young companies. In the public sector, however, universities and Public Research Institutions (PRIs) are active in terms of patent applications under the Patent Cooperation Treaty (PCT) and patents filed in emerging technologies. Despite the above weaknesses R&D expenditure in France has kept growing in nominal terms over the last decade, accounting to almost 50b in 2014 (only second to Germany in the EU28).

Over the last decades, the French Government has relied on a broad variety of industrial and innovation policy instruments which have been cumulating and overlapping in a complex and multi-layered policy mix. For example, alongside a generous R&D Tax credit scheme introduced in 1983 (CIR), France has been the second European country (after Ireland) to introduce the well-known Patent Box scheme in 2005. Moreover, since 2010, partially as a response to the global financial and economic crises, the government has launched a new set of research, innovation and sectoral strategies supported with significant funding allocations. In 2009 the French government launched the a ten-year plan called “Investments for the Future Programme” (PIA) 2010 - 2020 aimed at developing and transforming the French research and innovation system. It includes a number of strategic initiatives which aim to boost French competitiveness by investing in research, higher education and vocational training, in industry and SMEs, in sustainable development and in expanding sectors such as digital technology, biotechnology and nuclear energy.

In 2012 a "National Pact for Growth, Competitiveness and Employment" 2012 was also presented to revise a number of existing policy instruments (e.g. a reform/refocus of the Cluster Policy operating since 2004) and introduce new ones focusing on the emerging challenges of the French techno-industrial system (e.g. the implementation of new tax credit scheme for employment and competitiveness – CICE – or the creation of a new national public investment bank – Bpifrance). Among them, a new industrial strategy called "34 Plans for Industrial Renewal" (also known as the *"New Face of Industry in France"*) was launched partially drawing on the PIA and the "Filieres strategy" of the National Industry Council. The strategy was structured around 34 sector-based initiatives and phased within a roadmap implementation scheme. The first stage of this industrial strategy was made up of 34 plans to define innovation-focused strategies for industrial sectors, including the development of sectoral contracts in partnership with entrepreneurs and guidelines for funding bodies. In May 2015 this was reviewed and the second phase was reduced to 9 plans.

<table>
<tr><th colspan="3">FRANCE</th></tr>
<tr><th>Criteria</th><th>Strategic Targets</th><th>Instruments</th></tr>
<tr><td>Boosting markets</td><td>nano-electronics, medical devices, universal cars, aircraft (more)</td><td rowspan="2">• R&D Fiscal incentives
• Research tax credit (CIR)
• Innovation tax credit for SMEs
• Tax Credit for Employment and Competitiveness (CICE)
• Bpifrance
• Competitive clusters policy
• PIA (research loans, endowment, subsidies, co-funding)</td></tr>
<tr><td>Fixing markets</td><td>smart grids, thermal renovation of buildings, electric charging stations (more)</td></tr>
<tr><td>Creating markets</td><td>digital healthcare, high-speed train of the future, supercomputers (more)

Health and biotechnology (Bioinformatics, Biotechnology and Bioresources, Nano-biotechnology), additive manufacturing, virtual plant, internet of things, augmented reality.</td><td>• PIA (research loans, endowment, subsidies, co-funding)
• Centres for excellence
• Preindustrial Biotechnology Demonstrators
• National Infrastructures in Health and Biotechnology (Carnott Institutes, SATT, CVT, IRT, ITE)</td></tr>
</table>

Sustaining markets	renewable energies, environmentally friendly ships, green chemical and biofuels, water (more) Health and biotechnology (Bioinformatics, Biotechnology and Bioresources, Nano-biotechnology),	• PIA (research loans, endowment, subsidies, co-funding) • Centres for excellence • Preindustrial Biotechnology Demonstrators • National Infrastructures in Health and Biotechnology (Carnott Institutes, SATT, CVT, IRT, ITE)

Table 3: Targeting sectoral value chains: the case of France

Source: Author; see also Andreoni, 2017

The 34 sector-based priorities were explicitly selected on the basis of one (or a combination) of the following criteria:

- Boosting Markets: Exploiting competitive advantage and capturing global value
  The French government targeted a number of sectors that are either already large contributors to the economy and/or where analysis shows that there is likely to be significant increasing domestic and global demand that France has the potential to exploit, and where government involvement can have the greatest impact. These strategic sectors include: nano-electronics, medical devices, universal cars, and aircraft.
- Fixing markets: Addressing market and coordination failures
  The French government targeted sectors whose development has been significantly hampered by persistent market failures, including underinvestment in production capacity or lack of technological capabilities. The strategic sectors include: smart grids, thermal renovation of buildings, electric charging stations.
- Creating markets: Developing competitive advantage in emerging sectors
  The French government targeted emerging sectors (and underpinning technology platforms) in which the country wants to establish its presence and develop a competitive advantage. The strategic sectors include: digital healthcare, high-speed train of the future, supercomputers.
- Sustaining markets: Addressing future challenges
  The French government targeted sectors whose development is critical for achieving sustainable growth and addressing social and environmental challenges**.** The strategic sectors include: renewable energies, environmentally friendly ships, green chemical and biofuels, water.

5.3. Targeting the structural readiness of industrial ecosystems: the case of Germany

Germany is one of the world-leading and most diversified manufacturing nations, with manufacturing industries contributing over a fifth of the GDP. It is also the largest research and innovation system in Europe, with a total Gross Expenditure in Research and Development (GERD) in 2014 reaching 2.87% of the GDP, equal to EUR 83.9 billion. Germany alone accounts for 30% of all R&D expenditure in the EU28. Thanks to its export sector (and export basket composition), as well as its distinctive strengths in high-value manufacturing and technology systems, in comparison with many other countries Germany was relatively unaffected by the financial crisis, although since 2012 domestic demand has become the main growth driver. A number of countercyclical expansionary measures in public infrastructure, education and modernisation of the economic system also contributed to Germany's performances over the last years.

From mid-2000 Germany's industrial and innovation policy vision has been framed within a federal plan, called the "High-Tech Strategy" (HTS) (firstly adopted in 2006 and expanded in 2010). This is an overarching national innovation strategy aimed at coordinating (and exploiting complementarities across) the full spectrum of technology, innovation and manufacturing policies and regulations. The strategy was designed to address the new challenges posed by globalisation, but also to take advantage of the new opportunities in (i) health (medical technology and innovative services) and sustainability (resource-efficient and energy-efficient production processes); (ii) communication and mobility (including ICT, mechanical technologies and advanced materials for transportation); and finally, in (iii) a number of 'strategic partnerships' in cross-cutting activities where transversal opportunities were emerging (new 'platform technologies' and 'pioneer markets'). The strategy also recognised the need to match these new techno-industrial ventures with new regulations in intellectual property, product standards and concerning the governance of the public procurement system. The translation of this policy into specific programmes and measures, as well as their implementation, not only involved various Federal government ministries but also the landers and the municipalities. This multi-layered governance structure is made even more complicated by the presence of multiple types of institutions, both private and public, supporting the industrial sectors and technological innovations (see below). Between 2006 and 2013, the federal government has invested EUR 27 billion in the HTS. In 2014 the Federal Government enacted the "New High Tech Strategy" 2014-17, covering the legislative period until 2017.

In 2014 two prominent policy agendas were also launched, both framed within the New HTS. The "Digital Agenda" 2014-17 focuses on capturing the opportunities that digitisation presents to strengthen Germany's role as an innovative and highly productive economy. This agenda goes hand in hand with the "Industry 4.0 Platform", an initiative focusing on the ongoing transformation of modern industry and its future challenges and opportunities, in particular the new types of socio-technical interactions in manufacturing systems, the design of smart factories in a networked world, the internet of things and the new manufacturing-services interfaces. In 2015 another New HTS-related initiative – "Innovation for production, service and work tomorrow" – was launched and supported with a EUR 1 billion budget until 2020, to exploit the positive impact of digital production and services on employment. Also, as part of a broader reform and reduction of bureaucracy, in 2015 the federal government introduced a new law to promote innovative public procurement practices at all government levels. This opportunity is also explicitly mentioned in the New HTS and Digital Agenda.

Among the many policy instruments, the High Tech Strategy included a specific programme to support SMEs, called "Leading-Edge Cluster Competition". The scheme aimed at boosting the development of high-tech clusters and favouring the development of linkages. In 2015 the German *Expert Commission on Research and Innovation (EFI)* evaluated the programme and suggested to close it after its third round of competition (2012-2017). On the contrary, the successful "Central Innovation Programme for SMEs (ZIM)", provided more than EUR 3.9 billion grants for innovative investments since its start in 2008 and is expected to continue. The ZIM is only one of many non-repayable cash grants, loans and participation programmes supported by the German government (others are: ERP Innovation Programme, KMU Innovativ; Innovation vouchers go-Inno). Despite these multiple support programmes, and differently from other major industrial economies, Germany does not adopt any explicit tax credit scheme. Notwithstanding, according to the German income tax law, all current expenditures for R&D can be deducted from the taxable income, thus, they are de facto non-taxable. Moreover, capital assets and other intangible assets can be subjected to depreciation or a reduction in value.

The "New High-Tech Strategy" 2014-17 is an interdepartmental innovation policy combining interventions in multiple productive sectors and underpinning technology systems as well as the broader technology infrastructure and the broader social factors enabling innovation-driven economic growth. In particular, the overarching goal is "for good ideas to be translated quickly into innovative products and services" and "creative answers to the urgent challenges of our time – including challenges in such areas as sustainable urban development, environmentally friendly energy, individualised medicine and the digital society" (p. 2 New HTS). Not only does it cover a plurality of sectors, it also considers the entire innovation chain – from creative idea to implementation in new products and services – and thereby links all aspects and players within innovation processes.

The new High-Tech Strategy is based on five thematic issues in research and innovation cutting across sectors, each of them including set of priorities and indication around lines of policy action. The following table presents the five thematic issues and a selection of priorities.

1) Priority challenges with regard to value creation and quality of life
• Digital Economy and society • Sustainable economy and energy • Innovative world of work • Healthy living • Intelligent mobility • Civil security
2) Networking and transfer
• Strengthening the potential for innovation in science • Strategically expanding universities‘ opportunities for cooperation with industry and society • Closing gaps in commercialisation
3) The pace of innovation in industry
• Using the potential of key technologies for the benefit of industry • Strengthening innovative SMEs • Increasing the numbers of innovative start-ups
4) Innovation-friendly framework
• Assuring the supply of skilled personnel for technical and innovation oriented occupations • Better financing of innovations • Enhancing the legal framework and standards in the technical sphere • Providing more-efficient protection for intellectual property • Creating incentives via innovative public procurement
5) Transparency and participation

Table 4: New High-Tech Strategy in Germany: Thematic issues

Source: New High-Tech Strategy 2014-17

At its highest level, the strategy does not target any specific sector, instead it concentrates on thematic areas “that feature especially dynamic innovation and that hold potential for economic growth and prosperity” across the entire manufacturing system. Notwithstanding, within the German manufacturing system there are a number of high manufacturing sectors which are more prominently targeted and for which there has been some form of prioritisation. These are the ICT sector (specifically, in relation to the mechanical engineering sector, including machine tool/production engineering/industrial technology, within the “Industry 4.0 Platform”); microelectronics; energy sector; automotive sector; and health sector.

The following criteria have inspired the selection of these thematic issues and related sectors:

- Boosting Markets: Exploiting competitive advantage and capturing global value
  The German government targeted a number of sectors that are either already large contributors to the economy and/or where analysis shows that there is likely to be significant increasing domestic and global demand that Germany has the potential to exploit, and where government involvement can have the greatest impact, especially in relation to boosting industrial innovation. These strategic sectors include: ICT sector (digital technologies, in particular with respect to industry 4.0); mechanical engineering sector; microelectronics; energy sector, health and intelligent mobility (thematic issue 1), but also cross-cutting manufacturing system regulations (IPRs, standards, etc) (thematic issue 4).

- Fixing markets: Addressing market and coordination failures
  The German government targeted thematic areas which are traditionally affected by persistent market and coordination failures, including investment in basic research, commercialisation gaps and transfer of knowledge between science and business, nationally and internationally (thematic issue 2). From a financing point of view it also addressed problems associated with start-ups financing and SMEs investments in innovation (thematic issue 3).

- Creating markets: Developing competitive advantage in emerging sectors
  The German government targeted emerging sectors (and underpinning technology platforms) in which the country wants to establish its presence and develop a competitive advantage. The strategic sectors include: ICT sector, in particular digital technologies, internet of things, big data, smart services, smart data, cloud computing, digital networking, digital science, digital education and digital life environment, IT security (thematic issue 1).

- Sustaining markets: Addressing future challenges
  The German government targeted sectors whose development is critical for achieving sustainable growth and addressing social and environmental challenges. The strategic sectors include: health, intelligent mobility, renewable energies, green economy, bioeconomy, sustainable agricultural production, future of building and city of the future, sustainable consumption, innovative world of work; transparency and participation (thematic issues 1 and 5)

GERMANY		
Criteria	**Strategic Targets**	**Instruments**
Boosting markets	ICT sector (digital technologies, in particular with respect to industry 4.0); mechanical engineering; microelectronics; energy sector	• Fraunhofer-Gesellschaft Institutes • Grant-scheme for SMEs (ZIM) • EXIST, High-tech Start-Up Fund, ERP Startfonds, INVEST, IKT Innovativ • Bank for Reconstruction (KfW) • Grid access for green electricity producers •
Fixing markets	ICT sector (digital technologies, in particular with respect to industry 4.0); mechanical engineering sector; microelectronics; energy sector	• Fraunhofer-Gesellschaft Institutes • Grant-scheme for SMEs (ZIM) • EXIST, High-tech Start-Up Fund, ERP Startfonds, INVEST, IKT Innovativ • Bank for Reconstruction (KfW)
Creating markets	ICT sector, digital technologies, internet of things, big data, smart services, smart data, cloud computing, digital networking, digital science, digital education and digital life environment, IT security ICT for electric mobility, autonomics	• Mission-oriented public funding • Max Planck Society • Helmholtz Association • Fraunhofer-Gesellschaft Institutes • Grant-scheme for SMEs (ZIM) • KOINNO 'Competence Centre for Innovative Public Procurement • Bank for Reconstruction (KfW)
Sustaining markets	health, intelligent mobility, renewable energies, green economy, bioeconomy, sustainable agricultural production, future of building and city of the future, sustainable consumption, innovative world of work; transparency and participation	• Mission-oriented public funding • Max Planck Society • Leibniz Association • Fraunhofer-Gesellschaft Institutes • KOINNO 'Competence Centre for Innovative Public Procurement • Bank for Reconstruction (KfW) • Grid access for green electricity producers

Table 5: Targeting the structural readiness of industrial ecosystems: the case of Germany

Source: Author; see also Andreoni, 2017

The “Digital Agenda” 2014-17 assigned centrality to the ICT sector as the new main engine of innovation, job creation and productivity increase, as well as the main technology system which will enable the transition towards the industry 4.0. In 2014 the German ICT sector generated almost EUR 85 billion of economic value added (more than the traditional industries such as mechanical engineering or automotive) in a global industry generating a turnover of some EUR 228 billion. In Germany there are 86,000 companies and 900,000 employees in the ICT sector. For every 1,000 jobs created in the ICT sector, 941 additional jobs are created in upstream industries. It is also estimated that companies will improve their productivity by 30 percent with the transition to Industry 4.0.

6. Discussion and conclusions

Modern industrial economies are complex systems. Understanding their architecture and transformational dynamics – emergence, decline and renewal – calls for new frameworks and effective policy tools. The paper has introduced and systematised a number of these frameworks and tools, in particular focusing on innovative industrial renewal dynamics triggered by structural traverses in mature industrial ecosystems. We claim that these are becoming increasingly key areas for industrial policy intervention, beyond more traditional industrial and technology policies, especially in Europe and other mature industrialised economies.

Indeed, governments across Europe and beyond have been increasingly concerned about the social, economic and macro risks associated with de-industrialisation of their industrial economies. In response to these risks and challenges, we have been witnessing the emergence of new industrial policies and new ways of targeting structural dimensions of the industrial ecosystem. Particular emphasis has been given to the need for supporting key (often emerging) technologies as well as the development of new industrial ecosystems around new sectoral value chains. A number of policies have also targeted opportunities of structural traverses in mature industrial ecosystems, and shown the need for an integrated approach targeting the transformation of the overall industrial ecosystem architecture and its structural readiness.

Even when governments prioritise the same sectors and emerging technologies, their strategic targeting operates in different ways. In some cases governments support entire sectoral value chains, while in others they tend to target specific value chain segments and tasks associated with higher value addition. Governments can also target different types of entrepreneurial organisations within the same sectoral value chain, for example supporting the second and third tier suppliers with dedicated SMEs policies or the broader industrial ecosystem.

Governments rely on a variety of instruments combined in different policy packages including selective market regulations and standards, productive knowledge service provision and financial incentives. In some cases governments have provided direct funding, others have designated specific sectors or technologies to benefit from more favourable R&D tax credits. Governments have also co-funded R&D in targeted sectors and channelled resources in building up and strengthening the country's overall technology infrastructure.

In those industrialised economies affected by fast de-industrialisation, selective industrial policies will increasingly deal with supporting the transformation of mature industrial ecosystems and shaping, jointly with private sector initiatives, new structural traverses towards higher-value product segments. This requires selective reduction of the risks involved in critical technology investments, rebuilding of domestic manufacturing capabilities, and re-scaling of existing production capacity to suit the needs of the new technologies. These different, although complementary, goals can be achieved only with integrated packages of policy instruments. Their alignment and synchronisation is critical in shaping the development of the industrial ecosystems of the future.

References

Adner, R., Kapoor, R., 2010. Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations, *Strategic Management Journal*, vol. 31, 306-333.

Adner, R., Oxley, J., Silverman, B. (Eds.) 2013. *Collaboration and Competition in Business Ecosystems*. Emerald Group.

Amador, J., Cabral, S. 2014. Global Value Chains Surveying Drivers and Measures, European Central Bank Working Paper series, 1739, October.

Andreoni, A. 2014. Structural learning: Embedding discoveries and the dynamics of production, *Structural Change and Economic Dynamics*, vol. 29, 58-74.

Andreoni, A. 2016. Varieties of Industrial Policy: Models, Packages and Transformation Cycles, in Noman, A. and Stiglitz, J. (eds.), *Efficiency, Finance and Varieties of Industrial Policy*, New York, Columbia University Press.

Andreoni, A. 2017. Strategies for Emerging Technologies and Strategic Sectors, Background paper for the OECD Report *Next Production Revolution*, Paris, OECD.

Andreoni, A. 2017b. Financing Sustainable Industrial Transformations and Policies, Background paper for the UNCTAD Trade and Development Report, Geneva, UNCTAD.

Andreoni, A. and Scazzieri, R. 2013. Triggers of change: structural trajectories and production dynamics, *Cambridge Journal of Economics*, vol. 38, 1391-1408.

Andreoni, A. and Gregory, M. 2013. Why and How Manufacturing Still Matter: Old Rationales, New Realities, *Revue d'Economie Industrielle*, vol. 144, 17-53.

Andreoni, A. and O'Sullivan, E. (2014) 'Vectors of innovation in industrial ecosystems: The role of specialist production and engineering contractors in the co-detection and co-creation of opportunities', presented at the Edith Penrose Centenary Conference, SOAS – University of London, 14-15 November

Andreoni, A. and Chang, H-J. 2016. Bringing production and employment back into development, *Cambridge Journal of Regions, Economy and Society*, doi:10.1093/cjres/rsw029

Andreoni, A. and Chang, H-J. 2016b. Industrial policy and the future of manufacturing: theoretical reflections, *Economia e Politica Industriale*, vol. 43, 491-502.

Andreoni, A., Frattini, F. and 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

Andreoni, A. and Cantamessa, M. 2017. Entrepreneurial drivers, intermediary institutions and policy in regional industrial ecosystems: A comparative study of Emilia Romagna and Piedmont, Italy, Sitra working paper.

Arthur, B. 2014. *Complexity and the Economy*. Oxford, Oxford University Press.

Asheim B., Cooke, P., Martin, R., 2006. *Clusters and Regional Development. Critical reflections and explanations*. Routledge, London.

Babbage, C. 1835. *On the Economy of Machinery and Manufactures*, London, Charles Knight.

Becattini, G. 1989. Sectors and/or districts: some remarks on the conceptual foundations of industrial economics, in Goodman, E. and Bamford, J. with Saynor, P. (eds.), *Small Firms and Industrial Districts in Italy*, London, Routledge

Berger, S. 2013. *Making in America*. MIT Press, Cambridge MA.

Best, M., 1990. *The New Competition: Institutions of Industrial Restructuring*. Polity Press, Cambridge MA.

Best, M. 2013. Greater Boston's industrial ecosystem: A manufactory of sectors, *Technovation*, vol. 39-40, 4-13.

Breschi, S., Malerba, F., 1997. Sectoral innovation systems, in Edquist, C. (Ed.), *Systems of innovation: Technologies, institutions and organizations*. London, Pinter Publishers.

Brenahan, T. 2010. General purpose technologies, in Hall, B. and Rosenberg, N. eds., *Handbook of Economics of Innovation*, Amsterdam, Elsevier.

Brusco, S., 1982. The Emilian model: productive decentralization and social integration. Cambridge Journal of Economics 6, 167-184.

Brusoni, S., Prencipe, A. 2011. Patterns of modularization: the dynamics of product architecture in complex systems. *European Management Review,* vol. 8, 67-80.

Chang, H.-J. and Andreoni, A. 2016. Industrial Policy in a Changing World: Basic principles, neglected issues and new challenges, presented at the CJE 40 Conference, Cambridge, 14 July.

Dahmen, E. 1989. Development Blocks in Industrial Economics', reprinted in Carlsoon, B. and R. Henriksson, (eds.), *Development Blocks and Industrial*

Transformation. The Dahemian Approach to Economic Development, Stockholm: The Industrial Institute for Economic and Social Research.

Dosi, G., Freeman, C., Nelson, R.R., Silverberg, G., Soete, L., (Eds.) 1988. *Technology and Economic Theory*. London, Pinter Publishers.

Doussard, M. and Schrock, G. 2015. Uneven decline: linking historical patterns and processes of industrial restructuring to future growth trajectories, *Cambridge Journal of Regions, Economy and Society*, vol. 8, 149-165.

Enflo, K., Kander, A. and Schon, L. 2007. Identifying development blocks – a new methodology, *Journal of Evolutionary Economics,* vol. 18, 57-76.

Garnsey, E., 1998. The genesis of the high technology milieu: a study in complexity, *International Journal of Urban and Regional Research,* 22(3), 361-377.

Garnsey, E., McGlade, J., (Eds.) 2006. *Complexity and Co-evolution: continuity and change in socio-economic systems*. Cheltenham, Edward Elgar.

Garnsey, E., Leong, Y.Y., 2010. Combining resource-based and evolutionary theory to explain the genesis of bio-networks. *Industry and Innovation* 15(6), 669-686.

Gereffi, G. 2013. Global value chains in a post-Washington Consensus world, *review of International Political Economy*, 21, 9-37.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technological Forecasting & Social Change 74, 413-432.

Jovanovic, B. e Rousseau, P. 2005. General Purpose Technologies, in P. Aghion e S.N. Durlauf (eds.), *Handbook of Economic Growth*, vol. 1B, Amsterdam-Oxford, Elsevier B.V.,

Kamp, B. 2012 *Main Challenges and Impact of Emerging and Generic Technologies at the European and Global Levels and Their Policy Implications*, Report, Orkestra-Basque Institute of Competitiveness.

Lin, C-H., Tung, C.M., Huan, C-T., 2006. Elucidating the industrial cluster effect from a system dynamics perspective. *Technovation* 26, 473-482.

Markard, J., Truffer, B. 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework, *Research Policy*, vol. 37, 596-615.

Marshall, A. *Industry and Trade*. London, Macmillan.

Milberg, W. and Winkler, d. 2013. *Outsourcing Economics*. Cambridge, Cambridge University Press.

Noman, A. and Stiglitz, J. (eds.), *Efficiency, Finance and Varieties of Industrial Policy*, New York, Columbia University Press.

Penrose, E. 1959. *The Theory of the Growth of the Firm*. Oxford, Oxford University Press.

Piore, M., Sabel, C., 1984. *The Second Industrial Divide*. Basic Books, New York

Pitelis, C., 2012. Clusters, entrepreneurial ecosystem co-creation, and appropriability: a conceptual framework. *Industrial and Corporate Change*, vol. 21(6), 1359-1388.

Probert, J., Connel, D., Mina, A., 2013. R&D service firms: the hidden engine of the high tech economy?, *Research Policy* 42, 1274-1285.

Richardson, G. 1972. The organisation of industry, *Economic Journal*, vol. 82, 883-896.

Rosenberg, n. 1963. Technological change in the Machine tool industry, 1840-1910, *Journal of Economic History*, vol 23(4), 414-443.

Simon, H. 1962. The Architecture of Complexity, *Proceedings of the American Philosophical Society*, vol. 106(6), 467-482.

Sturgeon, T., 2002. Modular production networks: a new American model of industrial organisation. *Industrial and Corporate Change* 11(3), 451-496

Tassey, G. 2007. *The Technology Imperative*, Edward Elgar.

Tassey, G. 2010. Rationales and mechanisms for revitalising US manufacturing R&D strategies, *Journal of Technology Transfer*, vol. 35, 283-333.

Tassey, G. 2014. Competing in Advanced Manufacturing: The Need for Improved Growth Models and Policies, *Journal of Economic Perspectives*, vol. 28(1), 27-48.