

Pathways of regional transformation and Industry 4.0

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Pathways of regional transformation and Industry 4.0

Lisa De Propris^a  and David Bailey^b 

ABSTRACT

We explore the impact of technological changes brought in by the Fourth Industrial Revolution on local systems of industrial specialization. To do so we connect the Evolutional Economic Geography literature on regional diversification with the literature on systems change, notably the multilevel perspective (MLP) framework, expanding the latter with a place-based dimension enabling the application of technological transition to regional economies. Here, a local system's ability to transform rests on three capabilities: innovation capabilities, docking capabilities and translational capabilities. Building on these, we identify four transformative paths: an endogenous transformative path; a hyper-transformative path; an importation transformative path; and a regional obsolescence path. We stress that local systems are not locked into a particular pathway, with implications for place-based industrial policy.

KEYWORDS

Industry 4.0; Fourth Industrial Revolution; multilevel perspective; regional transformation; technology transitions

JEL O3, O14, R11

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INTRODUCTION


There is much debate around the emerging wave of 'Industry 4.0' technologies which many see as amounting to a Fourth Industrial Revolution (FIR) with extensive socio-economic disruptions (Benassi et al., 2020; Organisation for Economic Co-operation and Development (OECD), 2017; Schwab, 2016). Initial studies have examined – at a macro-scale – the impact of digital technology on jobs and skills (Autor, 2015), the mobility of global talent (Baldwin, 2019), trade and foreign direct investment (FDI) flows (Strange & Zucchella, 2017) and on environmental sustainability (Götz & Jankowska, 2017). At the micro-scale, there is a fast-moving debate on how digitalization and automation in particular will reorganize resources in the production process and the layout of factories (Ciffolilli & Muscio, 2018). However, the impact on regional economies of FIR technologies is yet to be investigated in depth.

This paper contributes to the debate by exploring the possible transformative paths local economies may face as new technologies shake the technological foundations of industries, value chains and thereby local systems of production. Core to the evolutionary economic geography approach (Martin & Sunley, 2006; Martin & Simmie,


2008) is the understanding that economic activities evolve along predetermined time and space coordinates (Boschma, 2015; Frenken & Boschma, 2007). Debates on regional industrial transformation and structural change (Grillitsch et al., 2018; Miörner & Tripl, 2017) have looked at the emergence and evolution of regional economies (Martin, 2010) and regional diversification (Boschma, 2017). Yet our understanding of industrial change and regional development is now challenged by the technological discontinuity introduced by the current wave of new technologies. This paper provides a first attempt to explore this issue and does so by questioning the impact on regions of the current technological revolution by exploring the links between new technologies, sectors and local economies. In so doing, we focus in particular on industrial local systems (spaces) where economic activities revolve around one main technology. Highly specialized regions might be home to one such industrial system, while more diversified regions might have many. In both cases, industrial local systems are likely to be shaken by emerging technological discontinuities that will redefine their division of labour and markets.

Technological discontinuities have been studied within the innovation literature in relation to system changes and

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transitions, in terms of technological regimes (Nelson & Winter, 1982), technological paradigms (Dosi, 1982), technological revolutions (Perez, 2010) and technological waves (Kondratieff, 1979). This literature postulates that although inventions (Schumpeter, 1942) might trickle through over time, they tend to cumulate and tip over in discontinuous technological jumps that disrupt the socio-economic system only at discreet intervals (Perez, 2010). More recently, within this literature, the multilevel perspective (MLP) (Geels, 2002, 2005) has emerged attempting to explain the dynamics driving transitions from one technological paradigm to the next. We extend the MLP framework to explain what transformational pathways local industrial systems might face in transitioning onto the new technological paradigm. We introduce a more developed place-based element to the MLP framework by suggesting in particular that regimes and niches must be grounded in places.

The paper proceeds as follows. The next section discusses the technological changes brought in by the FIR. The third section connects the Evolutional Economic Geography (EEG) debate on regional diversification with the literature on system change and transitions. The fourth section presents an expansion of the MLP framework by adding a place-based dimension that enables an application of technological transition to regional economies. Four paths of regional transformation are presented, with each illustrated by a case study. The fifth section discusses some policy implications.

THE FOURTH INDUSTRIAL REVOLUTION

The literature on systems change has explained technological change as shifts in technological regimes (Nelson & Winter, 1982), or of technological paradigm (Dosi, 1982), both driven by scientific discovery. The disruptive impact of technological revolutions is captured by the concept of technological waves (Kondratieff & Stolper, 1935), suggesting that radical innovations emerge over time driven by scientific discoveries, but that they cumulate and trigger technological change only when old technologies exhaust their potential. Once a new technological wave is released, it produces a multitude of incremental innovations that permeate many aspects of the economy and society, triggering a fundamental shift in the techno-economic paradigm (Perez, 2010). Kondratiev's long waves introduced discontinuities in technological progress, linked with cycles in the global economy. In this view, the disruption of new technologies in each wave fundamentally changes which resources are used and how they are used, as well as reshaping the organization of production, leading to a new phase of socio-economic growth. Each transition from an old technological paradigm to a new one tends to be uncertain, risky and painful as old skills, resources, knowledge and ways of life are relinquished or made redundant before new ones establish themselves and release their growth potential (Autor, 2015; Baldwin, 2019; Frey & Osborne, 2017; Lacity & Willcocks, 2015).

There is general agreement that we are currently witnessing the emergence of a new technological paradigm that will arguably help shape economies and societies for decades to come (Benassi et al., 2020; OECD, 2017). It is also well understood that the breadth and depth of the transformative impact to be expected from these new technologies will amount to a new (fourth) industrial revolution (FIR). Taking a broad view of the FIR, these new technologies can be clustered under three linked domains: (1) green and renewable technologies; (2) digital technologies (information and communication technology (ICT) and mobile technologies, additive manufacturing or 3D printing, artificial intelligence (AI), cloud computing, big data analytics, Internet of Things, advanced robotics, sensing, space technology and drones); and (3) new materials (biotech, nanotech, neuro-technologies) (De Propriis & Bailey, 2020; Culot et al., 2020). Whilst there is no consensus on what precisely constitutes the range of FIR technologies, the above technologies relate as well to the technology 'roadmaps' laid out by a range of European governments including France, Germany and Italy (Muscio & Ciffolilli, 2020; Santos et al., 2017).¹ The pervasive and disruptive nature of FIR technologies are expected to impact in a number of ways, including inter alia: changing the capital-labour ratio by redesigning the organization of production inside firms; impacting on employment; redrawing value chains both in terms of value creation functions and geographical presence; introducing new value creation parameters in firms' business models; creating new sectors and markets; and ushering in new demand and consumer needs (De Propriis & Bailey, 2020; Pereira & Romero, 2017). The seeds of some of these new technologies can be traced back to the mid-1980s, but only now are socio-economic systems beginning to absorb the extent of such disruptions. Although often referred to as 'Industry 4.0', 'Smart manufacturing' or the 'digital revolution', FIR technologies are broader and consequently may trigger a transformational shift in the techno-socio-economic paradigm attuned to a green economy and society (De Propriis & Bailey, 2020).

The disruptive and transformative changes of these new technologies can be broadly grouped in three areas. First, FIR technologies will likely reorganize production inside and across factories (an 'industry 4.0' element; Ciffolilli & Muscio, 2018) with a new balance between capital and labour due to the adoption of digitally enabled technologies, as well as rearranging production along the supply chain with a geographical recomposition of the location of activities in part due to much more blurred borders between services and manufacturing (a value chain recomposition element again linked to 'industry 4.0') (Šlander & Wostner, 2019). Second, it will create completely new industries, markets and consumption spaces (a new markets element). The myriad of applications generated from these new technologies will create new needs and markets, but also – it is hoped – trigger a decarbonization of the economy, towards a bio-based economy for sustainable life cycle expectations. Third, FIR technologies will introduce new business models (Götz & Jankowska,

2017) and a new innovation–production–consumption continuum. The deployment, for instance, of AI, big data and nano-technologies will expand the adoption of servitization and of closer co-innovation between producer and consumers through more efficient systems of ‘mass customization’ (Baldwin, 2019; De Propriis & Bailey, 2020).

Such transformative changes are expected to impact on the nature of industries and on the organization of industrial activities. Specifically, we explore the impact of technological changes brought in by the FIR on local systems of industrial specialization by connecting the EEG debate on regional diversification with the literature on technological transitions.

REGIONAL DEVELOPMENT PATHS AND TRANSITIONS

A debate that started in the 1990s on clusters, industrial districts and milieux shone a light on the benefits of industrial spatial specialization and concentration where specialization is intended as the ‘industrial identity of a place’ (Becattini et al., 2009) for market responsiveness, flexibility and innovation (Crevoisier, 2004; Porter 1990). Core to the evolutionary economic geography approach has been the understanding that industrial activities are place-based: namely, embedded in local ecosystems by agglomeration and external economies, the sharing of tacit knowledge and intangible assets, a fluid interaction between firms, institutions and society, and preferential access to dedicated and tangible assets (Becattini et al., 2009; Bathelt et al., 2004). The presence of these – generally speaking – local production systems weighed heavily in determining the performance of the regional economy where they are homed (Porter, 2000; Pyke et al., 1990). The specialization dividend started to be questioned when new studies showed that such production ecosystems evolve through time due to endogenous forces and exogenous shocks (Belussi & De Propriis, 2013; De Propriis & Lazzeretti, 2009) with the risk of decline being rooted in the very success that they achieved, due to institutional and technological lock-in (Blažek et al., 2019; Frenken & Boschma, 2007). The destiny of such localized industries has consequences for regional economies, depending on their degree of reliance on such specializations. The opportunity to avoid decline has been discussed in the literature on regional industrial path development where stories of renewal (Boschma & Frenken, 2011) paved the way for a wide literature on regional diversification. These observations were crystallized in the concepts of related and unrelated varieties (Asheim et al., 2011). It was argued that places and regions less dependent on specific specializations have a greater chance of evolving through organic changes by being exposed to other specializations based on related or unrelated technologies (Boschma & Frenken, 2011). Therefore the industrial composition of regional economies has been a crucial explanatory factor in understanding regions’ evolutionary paths: the concepts of related and unrelated

varieties have been the interpretative key to explain the decline, renewal or diversification of industries in regional spaces (Grillitsch et al., 2018; Martin & Sunley, 2006). The literature on industrial diversification is anchored in the understanding in EEG that economic systems change along evolutionary processes characterized by cumulative-ness, path dependency (Martin & Sunley, 2006) and irreversibility (Frenken & Boschma, 2007; Martin & Simmie, 2008). Regional change could therefore unfold along some possible development paths depending on their embedded knowledge and capabilities (Grillitsch et al., 2019; Grillitsch & Trippel, 2014). Some of these development paths are underpinned by incremental adjustments such as in the cases of path extension, path branching and path diversification (Grillitsch et al., 2018), as well as path upgrading or modernization (Isaksen et al., 2018) and path extension (Grillitsch et al., 2018; Isaksen et al., 2018). In contrast, new evolutionary paths include: (1) path importation or transplantation (Isaksen et al., 2018; Martin & Sunley, 2006), whereby new development paths emerge from new technologies and scientific discoveries (Isaksen et al., 2018) literally imported from outside the regional and (2) path creation when new paths are initiated by new industries emerging endogenously. Indeed the geographical scales at which evolutionary pressure are exercised is across local, regional and super-regional spaces: Grillitsch et al. (2018) helpfully distinguish between concrete and abstract spaces to underline the importance of linking concrete local industrial spaces with more abstract industry spaces that connect super-regional networks (Götz & Jankowska, 2017; Trippel et al., 2018).

This literature has examined regions’ evolution against a backdrop of stable and consolidated technologies as well as instances of path creation underpinned by innovations within the technological paradigm of the Third Industrial Revolution, whether accessed internally or externally (Trippel et al., 2018). The path dependency rationale of the evolutionary approach foresaw industrial change and therefore regional change as a fundamentally linear, irreversible and somewhat predictable process (Martin & Simmie, 2008). However, as argued at the beginning of this paper, technological change is currently occurring rather in a disruptive and discontinuous way, forcing our analysis to question what resources, processes and agents that industrial local systems can leverage to *transform* themselves thanks to or because of these new technologies. The evolutionary paths mentioned above (especially the path creation and path importation *routes*) are challenged by the transformative force of a shift of the technological paradigm, namely FIR technologies. In this paper we suggest reconsidering these paths but with the idea that the change is not evolutionary but rather revolutionary.

To understand the drivers and the dynamics of how the current shock is pushing for a transformative regional change, the literature on technological transitions and system change can provide helpful insights. In particular, the MLP framework suggests that successful transitions require the overcoming of barriers that extend well beyond

technological and economic dimensions (Geels, 2004, 2005), with a range of dimensions such as institutions, infrastructure and society being seen as just as significant.

The MLP literature explains technological transitions as shaped by interactions between three nested levels within the system: landscape, regime and niche. These form a nested hierarchy with niches embedded within regimes, which are in turn embedded in the landscape (Geels, 2005). There is no single cause or driver of change at work (Geels, 2011), but rather, there is ‘circular causality’ in which processes at different levels interact with each other.

Based on observing historical transitions, Geels and Schot (2007) posited a typology of stereotypical transition pathways: (1) a landscape that reinforces the regime, as against one that disrupts the regime; and (2) a niche and regime relationship that can be competitive or symbiotic. The timing of interactions also plays a key role, denoting the ‘readiness’ or ‘competitiveness’ of the niche based upon its development level. Using these criteria, four possible transition pathways were outlined (Geels & Schot, 2007).

The MLP framework focuses on technologies and therefore is largely space blind in its original conception (Gibbs & O’Neill, 2017; Smith et al., 2010). While the MLP framework’s three levels conceptually do not have a geographical dimension, Geels & Raven (2006) accept that landscapes, regimes and niches operate at the macro, meso and micro-scales, whilst niches straddle local and global scales (Geels & Raven, 2006). Also it is acknowledged that each level is characterized by systems of actors operating at different, although interconnected scales (Berkeley et al., 2017). Nevertheless, even in the MLP description of transition pathways (Geels & Raven, 2006), niches and regimes must meet somewhat on the same scale to allow system change to occur and, thereby, transitions are argued to be seen as processes connecting multi-scalar structures (Coenen et al., 2012). However, this issue is severely understated in the original MLP approach. This ‘naïve conceptualization of space’ (Coenen et al., 2012) in the original MLP approach was addressed when the latter was applied to study ecological transitions (Gibbs & O’Neill, 2017; Hansen & Coenen, 2015; Smith & Raven, 2012; Truffer & Coenen, 2012).² Indeed, Truffer and Coenen (2012, p. 15) note that cities and regions may emerge as ‘powerful promoters of sustainability transitions’. The debate on ecological transitions is still ongoing and has stressed that when the MLP framework is applied, space awareness becomes crucial.

PLACE-BASED MLP FRAMEWORK

In this paper we combine the EEG formalization of regional development pathways with the tenets of the MLP framework to understand the impact of new technologies (namely, FIR technologies) on industrial spaces. The novelty is to capture the transition of industrial local spaces. A first attempt to link the literature on MLP with economic geography borrowed the concepts of

regimes and niches from the MLP framework to explain regional *diversification* (Boschma et al., 2017). They identify four regional *diversification trajectories*, for example, replication, transportation, exaptation and saltation, by crossing regions’ existing industrial base (either technologically old (regimes) or new (niches)) with regions’ external shocks being either related or unrelated to their specializations. This contribution, however, fell short of spatially characterizing both niches and regimes, which is what we propose in this paper.

The starting point of our conceptualization of a place-based MLP is to take the three levels of socio-economic transition, that is, landscape, regimes and niches, and ground them in specific places. In particular, socio-technical landscapes capture the exogenous environment shaped by various mega-trends, macro-challenges and opportunities, sometimes powered by international pressures, national level policies or bottom-up movements for change. The landscape tends to spread across national and international scales and provide a backdrop for the way in which niches challenge existing regimes. Regimes are defined as the socio-technical meso scale at which systems of firms, research and stakeholders operate and land in specific places, regions, or cities. Technologies are applied in a variety of industries and each of these tend to cumulate over time in specific places, such as regions or localities, generating techno-industrial local systems of specialization. Such cumulation tends to roll out over the timespan of a technological wave. Industries are the destinations of the many applications coming out of a new technology as the latter is transformed in endless variations of new processes and new products in the diffusion stage of a new technological wave (Perez, 2010). We would argue therefore that the time–space concentration of cumulative specializations and branching within a defined technological regime culminates in techno-industrial local systems of specialization.

What distinguishes these systems from other well-known concepts such as industrial clusters, industrial districts and regional innovation systems, is that the focus here is on the technological nature of their specialization.³ Such industrial local systems co-evolve with the technology they embody. On the eve of a new technological revolution, such systems are formed and grow as specific applications of the emergent technology; their growth is mirrored by the density and the complexity of the system of firms and public and private stakeholders that over time thicken the socio-economic local mesh. As the underpinning technologies become mature, so do such systems and their growth slows down reaching a stage where the usefulness of the technological skeleton becomes time limited. The literature on industrial systems (Malerba & Orsenigo, 1997) argues that techno-industrial local systems of specialization in the same sector fall within the same industrial system to the extent that they face the same challenges and opportunities in terms of markets and technology.

Finally, niches are the sparks of new technologies, the embodiment of the exploratory and science driven

innovation that can occur outside the regimes, despite regimes, but aspiring to attract the attention of regimes. In line with Geels (2002), niches can be seen as incubation rooms for new radical innovations, namely for novelties that are far from market and adoption, and still at an exploratory level. In our model, we consider that niches are also place-based, which means they are created or emerge, and operate in very specific places depending on the innovation capability of that place. Knowledge creation requires actors that have extensive scientific knowledge at the frontier of their fields, have advanced research competences, and can function in conditions of high risk and uncertainty thanks to patient funding from public or private sources. Defined as such, the spatial context in which niches emerge and develop should not be overlooked; this is an extension to the stream of literature on strategic niche management that has looked at niches as 'protected spaces' for the development of new technologies emphasizing the link between science, sectors and markets (Kemp et al., 1998; Rip & Kemp, 1998). Being science driven, niches often start with knowledge that leads to radical innovations for which an industrial outlet is yet to be identified, and it may be unclear whether and when an avenue can open up for future applications. In their pure form, the novelties produced within niches can have potentially cross-sector and transversal applicability as is currently the case for emerging digital technologies or other key enabling technologies (KETs).

We describe the interactions between place-based regimes and niches by adapting the well-known representation of Geels (2002). We distinguish regimes from niches not only in terms of technological content, but spatially as they might be located in different places. As described in Figure 1, techno-industrial local systems of specialization represent industrial local systems within mature technological regimes, whilst niches emerge as incubators of new technologies that can be co-located

with a system or be spatially distant. Each bubble captures different techno-industrial local systems – each with its own location and systemic peculiarities; while the green squares represent the swarm of niches emerging first as highly transversal technologies and then finding more confined applicability as they are adopted with in local industrial systems.

REGIONAL TRANSFORMATIVE PATHS

The spatial alignment (convergence) or dis-alignment (divergence) between niches and regimes together with the spatiality of the technological shock (endogenous or exogenous) generate *four transformative paths*: endogenous transformation path, hyper-transformation path, importation transformation path and regional obsolescence path. We argue that the ability of industrial local systems in regimes to transform themselves rests on three crucial capabilities: *innovation capabilities* empower and equip systems to create internally new niches that can transform and renew the existing technology in a mature regime. The absence of internal and systemic innovation capabilities can be compensated by the presence of *docking capabilities*: these capture the attractiveness and receptiveness of a system for de-located niches to land in that particular place. Docking capabilities can lure niches seeking a landing platform and, at the same time, allow incumbent firms to signal a need to import new technologies. Whether reliant on internal or external innovation sources, the transformative capacity of industrial local systems in a regime rests on having *translational capabilities*, namely a high absorptive capacity to access and absorb radically new technologies, and further to develop new applications combining existing knowledge bases with new ones intrinsic to niches. This is illustrated in the Tables 1 and 2. Each transformative path is detailed below, with exemplary case studies presented (Figures 2–5).

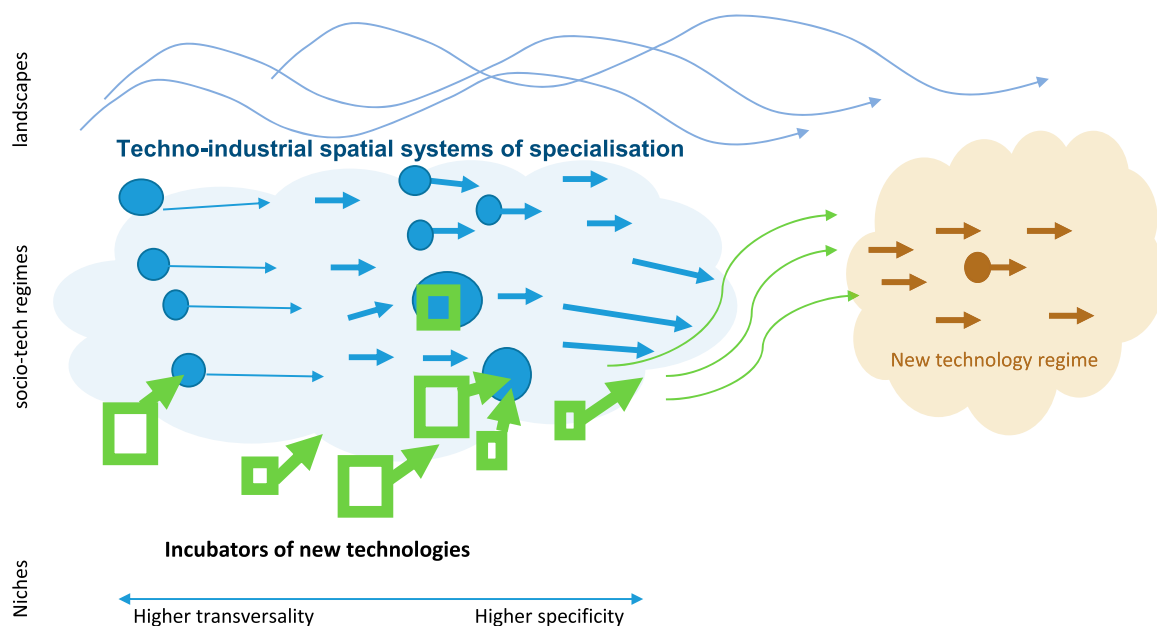


Figure 1. A place-based multilevel perspective (MLP) framework.

Table 1. Transformative paths (TP).

		Spatiality	
		Endogenous	Exogenous
Alignment regime-niche	Convergence	Endogenous TP and hyper-TP	Importation TP
	Divergence	Regional obsolescence P	

Regional obsolescence path

We can start with the extreme case of an industrial local system that is nested in a specific mature regime, and risks become locked into it and becoming obsolete. This occurs when businesses and local private and public stakeholders are unable or unwilling to consider radically new technological niches that are being developed related to the same ‘industry’, whether located inside or outside the system. The systemic resistance of the incumbent stakeholders to consider technological change in order to preserve the mature technology prevents the local system from exploring any possible avenues of technological change from which it is effectively decoupling itself. Such systems lack the sufficient innovation, docking and translational capabilities to capture the urgency of the change. Systems that persist along this path will disappear as eventually their underpinning technology will become obsolete. In **Figure 2** we represent the decoupling of the industrial local system from emerging niches – captured by the direction of the arrows – which might be developed by actors outside the system, for instance competitors, or by means of internal experimentation.

This defensive position can, however, be temporary, whereby systems remain on this path for a short period of time and jump on a new path of transformation by accessing technologies developed elsewhere, if there is enough landscape pressure for change (e.g., a change in regulation, a crisis situation etc.) or markets are already forming reducing the level of risk. The lag in adopting the new technology results in the system having to play catch-up and strategically assuming a follower position. The case of the German auto industry centred in Bavaria and Baden-Württemberg is considered below in this context.

The auto system in Bavaria and Baden-Württemberg

The German auto system centred in Bavaria and Baden-Württemberg can be viewed as a local industrial system on a path of regional obsolescence for a period of time until the ‘Dieselgate’ scandal of late 2015 forced an abrupt transformation, with it now playing catch up in battery

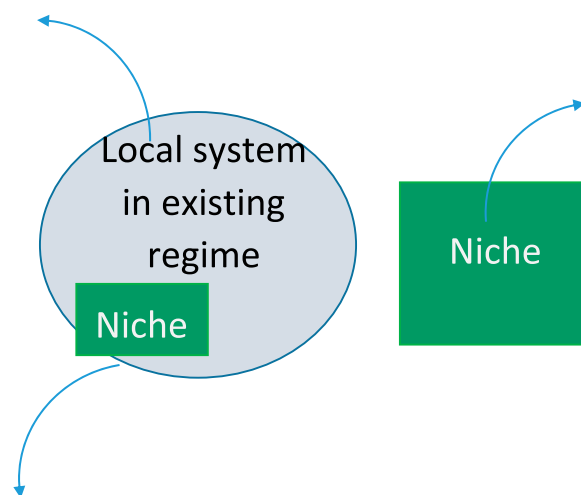


Figure 2. Regional obsolescence path.

electric vehicles (BEV) technology. The system had by the 1990s established a dominant position in the premium sector, with a reputation built on engineering and reliability. Yet that was not a position necessarily built on technological and organizational leadership in products. In many regards, German auto makers were technology followers, often lagging Japanese rivals. For example, lean production in the auto industry was pioneered over several decades by Toyota and deployed internationally by the 1980s; Volkswagen followed a decade later. Similarly, while Toyota launched its first hybrid model in 1997, VW did not launch a hybrid car until 2010. Where the German auto industry did lead was in the design and build of internal combustion engines (ICE) which suited larger premium models.

With the vast bulk of assemblers’ sunk costs related to existing ICE technologies, such firms saw investment in BEVs as highly disruptive. Manufacturers were reluctant to shift investment into BEV development, and retained an expectation that ICE vehicles would continue to become more efficient, with an institutional lock-in for conventional ICE vehicles. While this applied across much of the European industry (Van Bree et al., 2010), it was especially marked in this case in diesel technology. Six to seven years ago, leaders in VW in particular still saw BEVs as inferior despite Tesla already eroding German brands’ premium market shares. By 2015 the German system was lagging in terms of patents in key new technologies of electric mobility and with a supply chain firmly locked into ICE technology. It was also investing little in autonomous driving or mobility services, even though these were already seen as key elements of the future auto value chain. The system at this point was investing

Table 2. Transformative paths (TPs) and capabilities.

	Innovative capabilities	Docking capabilities	Translational capabilities
Endogenous TP	+	-	+
Hyper-TP	+	+	+
Importation TP	-	+	+
Regional obsolescence P	-	-	-

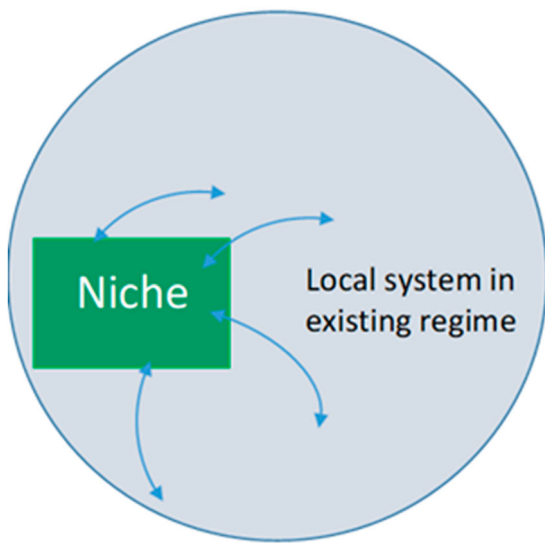


Figure 3. Endogenous transformative path.

heavily in ‘industry 4.0’ technologies in terms of smart factories but not in radically new BEVs as products.

It should be noted that some Japanese and American auto makers had gone down different technological routes in trying to reduce greenhouse gas emissions. Toyota had invested heavily in petrol hybrids, while Tesla and GM in the United States, and the Renault–Nissan alliance in Europe and Japan, had invested heavily in BEVs. The Bavaria/Baden-Württemberg auto system had effectively placed heavy technological ‘bets’ on what was increasingly seen as an obsolescent ICE (especially diesel) technology. This ICE regime lock-in was the result of a mix of factors, including large firm investment decisions, low fuel prices, the high willingness of customers to pay promoted by high levels of advertising expenditure, and not enough landscape pressure to force change (Clausen, 2018).

In late 2015 Volkswagen was found to have cheated emissions tests by installing illegal manipulation software in 11 million diesel cars. The resulting fall out undermined consumer confidence and accelerated a rapid consumer shift away from diesels. What became known as ‘Dieselgate’

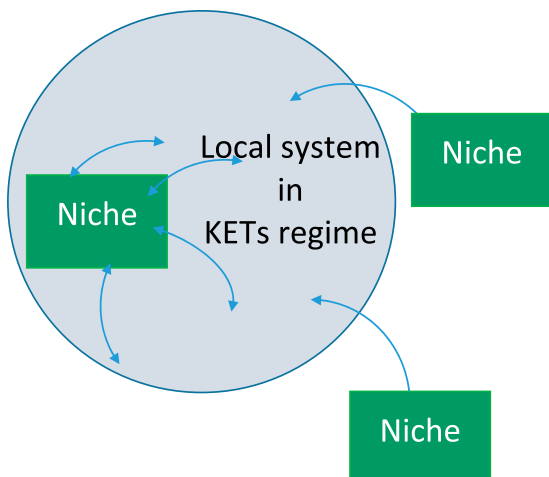


Figure 4. Hyper-transformative path.

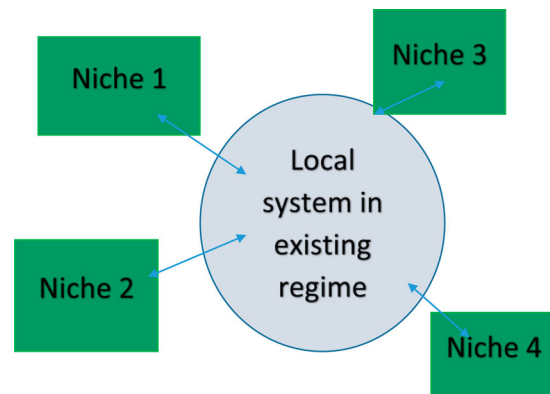


Figure 5. Importation transformative path.

forced the German auto system off a path locked into obsolescent ICE technologies. Indeed, combined with stricter new environmental and testing standards at the European level, this acted as a ‘wake-up call’ for Volkswagen, Daimler and, to a lesser extent, BMW, spurring them to refocus on future technologies – especially BEVs – and alternative business models. Post-Dieselgate, the German auto system has been playing catch up, investing heavily in BEVs as well as mapping, car-sharing, connectivity, autonomous vehicles and the infrastructure required for such technologies. Incumbent German original equipment manufacturers (OEMs) are now amongst the heaviest investors globally in BEVs, with VW investing tens of billions of euros in BEV technologies and infrastructure, aiming to sell 25% of its own-brand vehicles as BEVs by 2035. Heavy investment in its BEV platform has led Ford to partner with it to achieve scale economies in assembly. Germany has also attracted the disrupter firm Tesla to build batteries and BEVs in a new ‘gigafactory’ being built near Berlin.

Overall, the Dieselgate arguably ‘saved’ the German auto system (Kerier, 2018) by abruptly kicking it off a regional obsolescence path. Its cumulated embedded knowledge in auto manufacturing has nevertheless helped it jump from the ICE regime to the BEV one relatively smoothly and to become attractive to emerging niches looking for a landing spot, such as BEV pioneer Tesla (Bailey, 2015).

Endogenous transformative path

A second case considers an industrial local system that, despite being nested in a specific mature regime, is to be able to explore radically new ideas, and to generate, develop as well as incubate endogenously one or more niches. For this to occur, the local system must present sufficient endogenous innovative capabilities to stimulate exploration and experimentation that go beyond and challenge the underlying technological regime. Endogenously generated niches reflect exploratory learning processes occurring in local research organizations, start-ups or small firms, or the ‘skunk-works’ of embedded larger firms, and/or in blue-sky public funded projects housed in larger firms or business networks. These systems are able to gestate technological niches thanks to the dense scientific base made up of an infrastructure of actors and linkages that not only feed incremental innovations to

the local system during the growth phase, but are also able to start and incubate radically new ideas. In addition, they are able to attract risk-loving stakeholders and public funding. The bubbling of these experimentations at the margins of the core technology of the local system provide opportunities for radical transformations that at an early stage might well find resistance by the incumbent actors locked in the dominant regimes; however, finding themselves on the technological frontier, such niches are likely to be connected globally via research and scientific linkages, progressing at a pace that is therefore externally set and likely to be idiosyncratic with respect to the local system's internal receptiveness (translational capability). In the technological space that occurs as an old regime is sidelined by a new one, these systems find themselves as first-movers thanks to the endogenous technological capabilities that the internal niches present. These can in fact be deployed and inseminate the embedded regime with new solutions, challenging and disrupting the equilibrium of the socio-eco regime. Figure 3 describes the endogenous nature of new niches and the receptiveness of the industrial local system which is prepared to challenge its techno-industrial foundation to explore the niches' novelties. These mutant systems are able to embark therefore on an endogenous transformative path thanks to the technological niches that the system breeds and incubates. The case of the Midlands Low Carbon 'Phoenix Industry' is explored below in this context.

The Midlands low carbon 'phoenix industry'

The Midlands automotive system became 'locked-in' to core technologies and practices around the internal combustion engine and steel chassis development through a combination of complex supply chain arrangements, sunk investments in equipment, the existing skill set of the labour force and an industry-wide technological paradigm. As a result, incumbent actors tended to favour incremental innovation focused on the improvement of existing technologies. However, the range of technologies that are important to succeed in the industry has expanded in the light of landscape change in the form of environmental, regulatory and demand-led challenges – ranging from electronics, to digital, to new fuel and power technologies in the form of BEVs, and to light-weighting. As a result, the role of specialist suppliers of knowledge, research and development (R&D) and components has become crucial for innovations of a more systemic nature (Köhler et al., 2012). Under this view, more radical innovation, for example around BEV and fuel cell powered vehicles, has tended to be initially undertaken, 'within universities, by firms in other sectors or by enthusiastic amateurs, entrepreneurs or start-ups' (Köhler et al., 2012, p. 431). The automotive industry has tended to enter into partnerships with organizations outside the industry in order to be able to move beyond their core competencies and utilize expertise from outside the sector, in line with the combinatorial pathway identified above. However, this trend towards open innovation has also helped the emergence of a 'phoenix industry' centred on the UK's traditional automotive

heartland, the West Midlands in recent years, focused on low carbon technologies applied across a range of sectors (Amison & Bailey, 2014), which can be viewed more as an endogenous transformative pathway. So while in assembly terms the region's auto system is now largely reliant on relatively small-scale premium and luxury vehicle production plus a number of specialist niche firms, the system has diversified into design and engineering expertise with a focus on low carbon 'enabling technologies' applied in automotive, aerospace, transport more broadly, and construction. In the auto area, this includes: Jaguar Land Rover in the premium and upper premium segments; a network of first and second tier suppliers; a number of niche vehicle manufacturers; and a concentration of design, R&D and engineering consultancies plus university research expertise (Amison & Bailey, 2014). The public policy environment has also been supportive of the industry, for example through the work of the former regional development agency, Advantage West Midlands, in diversifying the cluster and more recently through the establishment of the Centre for Excellence in Low Carbon and Fuel Cell Technologies (CENEX), the 'High-Value Manufacturing Catapult' and 'Advanced Propulsion Centre in the region. These build, for example, on the 'Niche Vehicle Network' developed in the region on open innovation principles so as to facilitate low carbon technologies as enabling technologies across a range of sectors, building on long standing competencies in the region (Amison & Bailey, 2014). An interesting dimension is how actors have been assisted not only to reposition on the existing global value chain in terms of higher value tasks but also in terms of positioning on a completely new global value chain as the auto industry shifts into an era of autonomous connected electric (ACE) cars (Bailey et al., 2020).

Hyper-transformative path

Techno-industrial local systems of specialization in regimes characterized by one of the KETs linked to the FIR (KETs such as AI and digital technologies more broadly, biotechnologies, photonics or connectivity) can embark on what we call a hyper-transformative path. These systems are specialized in industries that by their nature are underpinned by transversal technologies, namely, technologies that can be utilized in a number of diverse industries underpinned by very distant technological and knowledge bases (Corradini & De Propris, 2017). These systems have hyper-transformative capabilities because not only they can seed endogenously new niches that are technologically radically new or aligned or evolving from existing ones, but they can also attract from the outside niches in industries and technologies that are diverse and distant from each other and those already present in the system. The magnetic force of these systems to draw in exploratory and far-seeing ideas to be developed and tested provides a constant and self-reinforcing stream of novelties. These in turn enable the local system to regularly jump across new regimes at a very early stage. We have represented the interaction between the local system

in a regime characterized by KETs and niches in Figure 4. Silicon Valley is discussed in this context below.

Silicon Valley: ICT, digital technologies and beyond

Silicon Valley (SV) has been the global hub in ITC technologies for almost seven decades with the constant presence of its universities, innovation infrastructure and public funding via the defence budget (Mazzucato, 2013). It started by converting its war-related aircraft industry in the 1950s into a space industry with specializations in electrical and electronics in the 1960s (Saxenian, 1983). What is SV today started to take shape in the same years with the emergence of the semi-conductor industry linked to defence. Its links with silicon, the material used to make micro-chips, is what gave the Valley its name. The latter grew quickly over the 1970s shifting more towards blending the semi-conductor technology with electronic communications, laser, microwave and computer technologies (Saxenian, 1990). By the 1980s SV was already a leading cluster in the manufacturing and R&D of integrated circuits. Against this backdrop, the 1980s saw the cluster mutating again from chip-making to making computer systems with companies such as Apple, Hewlett-Packard, and Sun Microsystems. At the turn of the century, it was already a world leader in information and communications technologies, but with an ability to seize emerging technologically related and unrelated opportunities.

Silicon is also used to make solar cells, and in the early 2000s cleantech was added to the suite of knowledge bases budding in the SV (Morton, 2006). Cleantech technology, like others before, was a *niche* in a system with its technological core well established in a *regime*. Morton (2006, p. 21) argues that, 'The business community [in SV] is not fazed by the small size of the solar market today – it's energized by the possibilities of tomorrow.' The imagination and inventiveness of the system has been witnessed many times over in spotting new and emerging technologies and to have the ingenuity to pursue them. Since the early 2000s, new niches in AI, robotics, augmented/virtual reality, software design and internet-based social networking are shifting SV's knowledge bases towards digital technologies.

As a leading industrial local system in the existing regime of ICT, SV owes its success to an ability to renew its core competencies constantly and incrementally thanks to endogenous innovation public and private capabilities, but crucially, also to augment and expand its knowledge bases by identifying, creating and developing radically new technological niches. A recent example of this ability to engage with new and diverse technological niches is the decision of the first fully electric car maker, Tesla, to locate its manufacturing and R&D in SV and not closer to the traditional automotive cluster in Detroit. The reason for this is that electric cars are increasingly digitally connected software and hardware on wheels, and needed therefore close proximity to leading digital technology providers. Second, as a decarbonized product

it made sense to locate close to leading cleantech firms. This latest augmentation in its knowledge bases has meant that more EV makers are now locating R&D department in SV decoupled from their manufacturing bases. For this, SV is an example of a local system on a hyper-transformative path.

Importation transformative path

There are techno-industrial local systems of specialization in existing regimes that do not have the internal capabilities to create and gestate niches. This does not mean that they lack innovation capabilities, as they might indeed have an innovation infrastructure with private and public research laboratories and research organizations, as well as access to public funding. However, this innovation set-up is unable to generate radical innovations. If the system is nevertheless wired, receptive, attractive and favourable to experimentation, it can attract external niches to anchor within it and pollinate its mature technologies within an existing regime, in so doing pushing a systemic transformational change. Its docking and translational capabilities allow the system to be open to become a technological 'hothouse' for new industries by wiring itself to globally dispersed carriers of frontier innovations.

Despite the absence of an endogenous ability to spur niches, at times of technological change, these local systems can 'lean over' and jump onto a new technological wave – new regime – because they have an ability to hook or pull relevant niches thereby radically transforming their technological foundation. These systems therefore import transformative technologies to shift to a new industry or to create a new market. The Jura Swiss watch cluster is an example of a system that is changing along an importation transformative path.

Jura's watches and wearables

Some of the most famous and valuable watches are made in Switzerland. Indeed, much has been written on the Jura Swiss watch cluster (Jeannerat & Crevoisier, 2011): it went through ups and downs whilst preserving a competitive position, with Swiss and Japanese watchmakers having the largest market shares (Donzé & Borel, 2019). Over time the cluster has increased its aesthetic and cultural dimensions so as to capture value and in so doing it has attracted luxury brands to locate in the region, and more recently it has relied on cultural activities enabling the co-production of branding activities (Jeannerat & Crevoisier, 2011). In this regard, policymakers have identified and developed a 'place brand' which differentiates and 'positions' the cluster in a positive way from its competitors (Bailey et al., 2020).

However, the cluster's biggest threat might be yet to come. Digitalization has been highlighted as one of the main challenges for the cluster (Deloitte, 2017); this warning has included recommendations to develop e-commerce. Much less of a concern for the cluster has been the emergence of new products in the market, in the form of smart watches. However, wearables products, including smartwatches, have become one of the fastest

growing new industries globally (PwC, 2016). In 2018, Apple sold 30.7 million units (up 36%), whereas the Swiss watch industry only sold 21.1 million watches (down 13%) (Forbes, 2020), casting a shadow on traditional watchmaking, of which Swiss brands occupy the luxury top end. The Apple smartwatch emerged as a niche in the digital technological regime that dominated SV; and it was conceived as a miniature smartphone strapped on the wrist with functions from emails to tracing ECGs, with ‘telling the time’ being a relatively marginal function. Nevertheless, this radical innovation is turning the watch industry on its head. Some of the most famous Swiss brands have started exploring this new market and teamed up with hardware and software digital providers from California to design their first smart timepiece. Tag Heuer is one of them: it accesses Internet of Things technology from Qualcomm in California by using its Snapdragon smartwatch platform (see www.wearable.com) and running the android smartphone technology by Google Wear Operating System. Tag Heuer launched its first-generation smartwatch in 2015 with some basic additional connected functions, but its first real smartwatch, with wellness and health functions (e.g., heart monitor), fitness, Global Positioning System (GPS), compass and gyroscope came out in 2020. The same has been attempted by other Swiss watchmakers with similar strategies, that has seen the traditional watch ‘teched-up’ with smart functions previously delivered by mobile devices. Two considerations are worth making here. One is that Swiss watchmakers are entering a completely new market by augmenting with new digital functions a traditional product (analogue) whose technology is rooted in the declining regime characterizing their industrial system. The second is that the indigenous innovative capabilities of the Swiss watchmaking system were uniquely geared towards quality, materials and personalization as against functionalities, and it failed to see the links between mobile communications and watches endogenously. Their ‘tech-up jump’ therefore required teaming up with radical innovators representing relevant niches, albeit located elsewhere.

CONCLUSIONS AND POLICY IMPLICATIONS

This paper has sought to explore the impact of technological changes brought in by the FIR on local systems of industrial specialization that characterize regional economies. To do so we have connected the EEG literature on regional diversification with the literature on systems change, and in particular, Geels’ MLP framework. We have expanded the conceptualization of the MLP framework’s levels, that is, landscape, regime and niche, by adding a place-based dimension that enables an application of technological transition to regional economies. The place-based MLP that we introduce assumes that regimes have clear technological specificities that are applied to a particular local industrial system; at the same time, niches are technological challenges that can be introduced by

actors embedded in the same local industrial system or externally imported. Industrially diversified regions can present more than one regime, whereas highly specialized regions would have one regime only. Therefore, the transformation force of FIR technologies will play out differently across localities and regions (De Propriis & Bailey, 2020), and this will have implications for the focus of and the innovation aspirations of a *transformative place-based industrial policy*.

We suggested that the ability of a techno-industrial local system in a regime to *transform* itself rests on three crucial capabilities: innovation capabilities, docking capabilities and translational capabilities. Depending on the above, we identify four transformative paths: the endogenous transformative path, the hyper-transformative path, the importation transformative path and the regional obsolescence path. Techno-industrial local systems are not locked in any of these pathways, but strategic decisions and investments by key business or institutional actors can move a system from one path to another. The spatial and systemic nature of regimes – captured by the term local systems of industrial specialization – recognizes the role played by businesses, public and private stakeholders in shaping the composition and dynamics of innovation capabilities, docking capabilities and translational capabilities.

A transformative place-based industrial policy needs, therefore, to ‘join up’ technologies, sectors and places, and in ways that recognizes possibilities for regional transformation pathways. A first challenge is to acknowledge the necessity of policy interventions for a *transformative* entrepreneurial discovery as against one more aimed at incremental upgrading. Fostering a process of transformative discovery so as to identify opportunities and challenges (Rodrik, 2004, 2008) allows overcoming resistance and inertia, as well as the *unlearning* of obsolete routines and know-how (Bellandi et al., 2021). This implies new forms of technology policy to ensure that the ‘general purpose’ nature of new technologies reaches different sectors and regions through initiatives of awareness raising, diffusion, adoption and emulation. Second, at the firm level, such technological jumps require significant capital investment that need to be encouraged both by raising awareness of the possibilities of new technologies’ applications, and financially with investment vouchers (Valbonesi & Biagi, 2016). Third, at the systemic level, the concerted activation of public and private stakeholders should aim at transforming the nature and the levers of the services offered to firm in the form of club or semi-public goods (Bellandi, 2006). These could comprise for example: skills and (re-)training policies; access to finance and risk capital for small and medium-sized enterprises; regional policies to support the reshoring and onshoring of supply functions and, as supply chains are fundamentally altered by technological adoption, supply chain initiatives that can encourage the creation of new functions that rebuild or reshape buyer–supplier linkages. Overall, the scale and speed of the challenges posed by the FIR bring into focus both the need and possibilities for a broader canvas

on which to design transformative place-based industrial policies that help regional economies with its localized specialization to shift from one regime to the next.

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NOTES

1. The Italian government, for example, offers a comprehensive classification of nine industry 4.0-enabling technologies ranging across new manufacturing solutions to cloud computing and big data analysis (Muscio & Ciffolilli, 2020). Take up of Industry 4.0 support for small and medium-sized enterprises has been analysed by Coro' and Volpe (2020).
2. Such work includes Dewald and Truffer (2012) on the development of the photovoltaic industry in Germany; Hodson and Marvin (2012) on the management of urban sustainability in Manchester; Bridge et al. (2013) on the energy market; and Yang et al. (2021) on sustainability transitions in Chinese provinces.
3. The 'industrial districts' literature has stressed the importance of social ties, tacit knowledge and informal relationships between firms and institutional stakeholders; whereas the clusters' literature underlines the buyers-suppliers linkages scaffolding the local value chain; again, the regional innovation literature points to the crucial role of innovation capability and the channels connecting innovation and diffusion.

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