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Technological revolutions, socio-technical transitions and the role of agency: Värmland's transition to a regional bio-economy

Paulina Ramirez

ABSTRACT

The paper draws on the literatures on techno-economic paradigms and socio-technical transitions to analyse the impact of technological revolutions on regional development. Based on interview data collected from policymakers and regional firms, the paper adopts a multi-scalar approach to analyse the role of agency and strategy formulation in the emergence of a new bio-based techno-economic paradigm and the early stages of a process of socio-technical transition towards a forest-based bio-economy in the Värmland Region of Sweden. The paper contributes to an understanding of the role of strategic agency in new regional path creation in the context of radically technological change.

KEYWORDS

technological revolution; socio-technical transitions; bio-economy; regional path creation; multinationals; innovation policy

JEL O, O3, O33, O38

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INTRODUCTION

The new wave of interconnected technologies associated with the terms Industry 4.0 and Industry 4.0+ (De Propris & Bailey, 2020) are associated with significant changes to existing scientific and technological knowledge, industrial organization, markets, as well as societal institutions and have the characteristics associated with technological revolutions (TRs) (Geels, 2004, 2011; Perez, 2010). These periods of radical transformations give rise to many interdependent clusters of radical and incremental innovations that profoundly transform existing systems of innovation and production at different spatial levels. These transformative processes are driven both by the emergence of new industrial sectors as well as the direct and indirect effects new technologies have on existing industries (Freeman & Perez, 1988). TRs are, therefore, associated with *system change* (Geels, 2004, 2011) rather than radical or incremental change within existing technological systems.

TRs are triggered by changes in the knowledge base of industries that are global rather than local in character so that processes of change take place across spatial boundaries and require multi-scalar approaches to understand critical elements of their developments. Potentially, the impact of TRs on regional economies can be one of profound transformation creating opportunities for new regional growth paths and regional system change (MacKinnon et al., 2009). However, despite their potential for growth, TRs have different regional manifestations and their impact on regional economies is uneven (Boschma et al., 2017; Coenen & Truffer, 2012; Hansen & Coenen, 2015; Trippl et al., 2018).

In order to understand the impact of TRs on local economies, regional scholars have engaged with the literatures on TRs (De Propris & Bailey, 2020) and socio-technical transitions (ST transitions) (Boschma, 2017; Boschma et al., 2017; Truffer & Coenen, 2012) which focus on the complex, co-evolutionary dynamics underpinning technological, industrial and societal transformations brought about by TRs. As suggested by Truffer and Coenen (2012), to understand regional development in the context of radical technological change, it is necessary to integrate our understandings of socio-technical and socio-spatial transitions.

Recent regional literature on new regional growth paths has emphasized the importance of local industrial structures, knowledge and collective learning processes, as well as place-based networks and institutions in the emergence of new industrial development paths (Isaksen & Trippl, 2017; Martin & Sunley, 2006; Morgan, 2007; Neffke et al., 2011; Tödtling & Trippl, 2005). Interests has focused on the conditions that stimulate the renewal of existing regional industries and the creation of new ones (Trippl et al., 2018) and a number of typologies

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have been proposed to distinguish between different types of regional development paths (Boschma, 2017; Boschma et al., 2017; Castaldi et al., 2015; Frenken et al., 2007; Frenken & Boschma, 2007; Grillitsch et al., 2018; Isaksen, 2015; Martin & Sunley, 2006). More recently, regional scholars have acknowledged the importance of agency, future expectations and visions in regional transformation (Ashein et al., 2019; Hassink et al., 2019) and a number of typologies of agency have been suggested.

Less attention has been given in the literature to the *dynamics* of regional transformation, so that path creation appears to be the rational outcome of a given set of specific conditions rather than the result of socially complex, contested and negotiated processes. Therefore, despite recent attention to the role of agency in regional transformation, *how* agents influence complex and contested processes of change require further study. At the same time, the regional literature has not discussed how the specific characteristics of the technologies underpinning new regional growth path can influence the trajectory of industrial development.

The paper draws on the work of Freeman and Perez (1988; Perez, 2002, 2010) on techno-economic paradigms (TEPs) and the more recent literature on multilevel perspective (MLP) and socio-technical transitions (ST transitions) (Dewald & Truffer, 2012; Geels, 2004, 2005) to develop insights into how TRs and ST transitions impacts regional path creation. The paper analyses the role of agency and strategy formulation in the emergence of a new TEP based on the development of new bio-materials and the early stages of a process of ST transitions towards a forest-based bio-economy in the Värmland Region of Sweden. Bio-economies are included in De Propris and Bailey's (2020) conceptualization of Industry 4.0+, which refer to technologies that trigger a transformational shift in the techno-socio-economic paradigm attuned to a green economy.

The paper is organized as follows. The second section discusses the literature of TRs, TEPs and ST transitions. The third section discusses existing work on new regional development paths. The fourth section discusses the methodology adopted in the study. The fifth section discusses the results. The sixth section concludes.

TECHNOLOGICAL REVOLUTIONS AND ST TRANSITIONS

To understand the key characteristics of TRs and how they may impact regional growth paths, we engage with the work of Freeman and Perez (1988), De Propris and Bailey (2020) and Perez (2002, 2010) on TEPs as well as insights from studies of ST transitions (Dewald & Truffer, 2012; Geels, 2004, 2005). Whilst these two literatures are complementary, they differ in terms of scope. Whereas Freeman and Perez (1988) centre their analysis on macro processes and the impact of radical technological change across industries, the literature on ST transitions provides more detailed studies of specific sectoral dynamics and the challenges associated with the emergence of environmentally sustainable industrial systems. Neither approach, however, incorporates a spatial perspective in their analysis.

In the work of Freeman and Perez (1988), TEPs refer to configurations of *pervasive technologies*, methods of production, economic structures and institutional systems that affect all industrial sectors and are stable over long time periods. Innovation within existing TEPs follows established trajectories and are therefore path dependent. TRs are defined as radical breakthroughs in scientific knowledge which give rise to new TEPs that transform the whole fabric of the economy and society (Perez, 2002, 2010). One important characteristic of new TEPs relevant to our discussion is that they have a major impact on what Perez (2002, 2010) calls *motive* and *carrier* industries. Motive industries are those that produce inputs with pervasive applicability (e.g., oil, semiconductors). Carrier industries are the most active users of the new inputs. A second important characteristic of TRs is that they profoundly reconfigure industrial boundaries and networks as they regenerate existing industries and give rise to new sectors (Perez, 2002, 2010). Similarly, the MLP literature has developed the concept of ST regimes which refers to configurations of firms, knowledge and technologies, markets and institutions that fulfil a societal function (e.g., transport, energy) (Dewald & Truffer, 2012; Geels, 2004, 2005). ST regimes are coherent and stable socio-technical configurations where innovation develops in incremental and path-dependent ways. The MLP literature has developed a complex framework that highlights the multidimensional complexity of ST transition and system change (Geels, 2004, 2005, 2010). In this framework, radically new socio-technical industrial configurations emerge in *niches*, understood as protected spaces (e.g., research and development (R&D) laboratories, subsidized demonstration projects) which are consciously created as locations for collective learning and the building of new social networks that contribute to the creation of *visions* and the management of expectations which guide the development of new technologies (Coenen & Truffer, 2012; Geels, 2004; Simmie, 2012; Smith & Raven, 2012).

A critical contribution of both approaches is their understanding that TRs and ST transitions are difficult and contested processes. One reason for this are the high levels of technological and market uncertainty in the initial stages of new-to-the-world technologies (Nelson & Winter, 1982). The second reason is that TRs and ST transitions typically pose a threat to vested interests and disrupt existing socio-technical systems based on aligned strategic benefits (Freeman & Perez, 1988; Geels, 2004, 2011; Perez, 2002, 2010). Moreover, radical socio-technical innovation requires the mastery of new knowledge, the reconfiguration of networks, and the creation of new markets and institutions which demand significant strategic reorientation on the part of incumbent firms and are often resisted (Geels, 2011). TRs and ST transitions, therefore, entail complex and contested processes of co-evolution of new technologies, markets, institutions and visions (Perez, 2002).

Only when new strategic alignments are achieved and enabling contexts are established, can the full wealth-creating potential of TRs be deployed (Freeman & Perez, 1988; Geels, 2010; Perez, 2002, 2010). These

new alignments, however, are established in the context of unequal power relations, resources and opportunities (Freeman & Perez, 1988; Perez, 2002). The critical point to highlight here is that new TEPs and ST regimes are actively constructed and involve social, political, and ideological confrontations and compromises that shape the emergence and diffusion of TRs (Geels, 2011; Perez, 2002). They therefore involve social agency (Geels, 2011).

In the MLP literature, agency can come from firms, industry bodies, engineers and researchers, policymakers, consumers and civil society (Geels, 2011). An important assumption is that agents operate under conditions of bounded rationality and trial-and-error learning, a critical point given the highly uncertain character of radical innovation. Another key idea is that socio-technical systems change because the strategies of key actors shift as a result of social action (Geels, 2004). Collective learning and 'mindful deviation' therefore create the conditions for new alignments between heterogenous actors.

Two critical actors that can provide agency are powerful incumbent firms and the state. Existing ST regimes are usually dominated by large firms – usually multinational enterprises (MNEs) – that possess large 'complementary assets' (e.g., specialized manufacturing capabilities, access to distribution channels). Although incumbent firms are unlikely to be the initial leaders of system change, their early involvement accelerates system transitions if they support innovations with their complementary assets (Geels, 2011). The role of the state and policymaking system and an explicit recognition of the political nature of ST transitions has recently assumed greater importance in the transitions literature (Geels, 2011; Schot & Steinmueller, 2018; Coenen et al., 2015). An important development is the notion of 'directionality' in public policy which argues for a new framework for science, technology and innovation policy that actively directs industrial transformations to the solution of societal 'grand challenges'.

Neither the TR nor the MLP literature discuss the role of place in technological change. TEPs and ST regimes are analysed as novel in global terms, but the nature and speed of their diffusion through society are not analysed in the context of the specific social relations that exist in different territories. Empirical work based on case studies, however, shows that ST regimes have different local manifestations (Boschma et al., 2017; Coenen & Truffer, 2012; Hansen & Coenen, 2015). Given that TRs and ST regimes are global in character but differ in terms of their local dynamics, a multi-scalar approach is needed to study their processes of diffusion across space (Coenen & Truffer, 2012; Dawley, 2014).

REGIONAL PATHS CREATION

Whilst innovation scholars focus their analysis on the characteristics and dynamic of TEPs and ST regimes and the demands new technologies make on societal structures and relations, regional scholars start their analysis of regional growth paths from the characteristics of regions. Regional studies emphasize the importance of existing local industrial structures, knowledge and collective learning processes, as well as place-based networks and institutions in shaping the emergence and evolution of new industrial development paths (Isaksen & Trippl, 2017; Martin & Sunley, 2006; Morgan, 2007; Neffke et al., 2011; Tödtling & Trippl, 2005). Interests focuses on the conditions that stimulate the renewal of existing regional industries and the creation of new ones (Trippl et al., 2018).

A number of typologies have been suggested to distinguish between different regional industrial growth paths (Boschma, 2017; Boschma et al., 2017; Castaldi et al., 2015; Frenken & Boschma, 2007; Frenken et al., 2007; Grillitsch et al., 2018; Isaksen, 2015; Martin & Sunley, 2006). *Unrelated path diversification* and *path creation*, when the new knowledge is not only new to the region but also new to the world, are the closest to the notions of TRs and ST transitions as discussed above. Unrelated diversification occurs when firms in a region create or move into new industries by combining their existing knowledge and competencies with previously unrelated knowledge, thereby opening significantly new development paths (Castaldi et al., 2015; Grillitsch et al., 2018). Path creation, on the other hand, refers to the emergence of entirely new-to-the-world industries based on new scientific, technological and organizational knowledge. New growth paths, however, often emerge in the context of existing industrial structures and institutional systems so the creation of new industries often rests on resources and competencies already rooted in the region (Martin & Simmie, 2008).

One important element in the development of new industrial growth paths is the nature of regional innovation systems (RISs). Isaksen and Trippl (2017) distinguish between *organizationally thick and diversified RIS* and *organizationally thick and specialized RIS*. Organizationally thick and diversified RIS are characterized by heterogenous industrial structures, strong scientific institutions that facilitate innovation in different technological fields, and diverse and geographically open knowledge networks. Organizationally thick and specialized RIS, on the other hand, host strong clusters in only few industries, knowledge organizations tailored to the region's narrow industrial base and specialized regionally oriented networks (Tödtling & Trippl, 2005). Therefore, though organizationally thick RIS may have the learning capabilities and the social and institutional infrastructure to develop radically new industrial paths, the strong competences and interdependencies of RIS actors in existing industries can become obstacles to path creation. Asheim et al. (2019) argue that these RIS are typical for old industrial areas and tend to support development along existing trajectories rather than the emergence of new growth paths.

Regional unrelated diversification and path creation can be galvanized by factors such as the existence of local universities with excellent scientific infrastructure and the availability of highly skilled workers (Asheim et al., 2019; Isaksen, 2015; Neffke et al., 2018; Trippl et al., 2018). The ability to access new knowledge from outside the region often plays a significant role in local

path creation (Martin & Sunley, 2006; Trippl et al., 2018). Critical factors to consider are the absorptive capabilities of the existing industrial base (Tödtling & Trippl, 2005), the embeddedness of foreign firms in the local economy (Martin & Sunley, 2006), and the degree of *strategic coupling* between regional growth strategies and the strategic needs of MNCs (Coe & Yeung, 2015). The discussion therefore highlights the importance of mutually reinforcing interactions between local and non-local actors. Though the regional literature acknowledges the importance of agency, strategic purpose and deliberate action in new regional path formation (Martin & Sunley, 2006), until recently the role agency had not been incorporated into the analysis (Boschma et al., 2017; Dawley et al., 2015; Hassink et al., 2019; MacKinnon et al., 2009; Rodríguez-Pose, 2013; Simmie, 2012). More recent literature has turned its attention to different types of agency and their impact regional development (Sotarauta & Pulkkinen, 2011; Grillitsch & Sorarauta 2020).

From the point of view of new path creation, a critical difference is that between *firm-level* agency and *system-level* agency (Asheim et al., 2019). Firm-level agents start new ventures and innovate in terms of products/services, production processes and intra-firm work systems (Sotarauta & Pulkkinen, 2011). These agents are critical for new path creation but do not necessarily bring about system change. System-level agency contributes to altering the conditions for industry in a region by changing the RIS and therefore play a strategic role (Asheim et al., 2019; Simmie, 2012). This includes changes in the knowledge infrastructure, the network structure and in institutional frameworks; changes that imply collective action (MacKinnon et al., 2009). The RISs and Triple Helix literature have identified numerous system-level agents such as universities, business organizations, and large firms. A less discussed actor in new regional path creation is the state and public sector agencies and their impact on regional institutional capacity in terms of resources, expertise, leadership, and institutional relationships (Boschma et al., 2017; Dawley, 2014; Dawley et al., 2015; MacKinnon et al., 2009; Rodríguez-Pose, 2013; Simmie, 2012). More recently, Asheim et al. (2019) and Hassink et al. (2019) have drawn attention to the need to integrate into regional analysis the role of future expectations and visions and how these shape the emergence and development of path creation.

Despite significant advances in our understanding of the conditions required for the emergence of new growth paths and the characteristics of different routes of industrial development, how new regional growth paths emerge and develop is still unclear (Asheim et al., 2019; Boschma et al., 2017). Insights from the technology and innovation literature can help deepen this understanding (e.g., Castaldi et al., 2015). One important element from the literature on TRs and ST transitions that could be better integrated into the analysis of regional development is the specific characteristics of new technologies and the manner in which they reconfigure industries and their boundaries, including how their forward and backward linkages open the way to processes of unrelated diversification. The characteristics of specific technologies and how they shape industrial growth paths is not generally discussed in the regional literature, yet studies of TRs and ST regimes show this is a critical factor in the dynamics of industrial rejuvenation.

Much of the literature has focused on the character of regional industrial structures and knowledge and has offered different typologies of RIS and growth paths; less is known, however, about the *dynamics of system change*. This lack of a *process view* may explain the dearth of attention to the socially complex, contested and negotiated character of regional system change which highlights the importance of agency and regional strategies able to align different regional interests and mobilize resources to new path creation. This appears to be particularly important in the initial stages of path creation based on new-to-the-world technologies when the trajectory of development is not clear.

The paper adopts a process approach to analyse the early stages of an emerging transition in the Värmland region of Sweden from an economy dominated by the traditional pulp and paper industry towards a bio-economy. The analysis explores three questions:

- The nature of agency and strategy in the initial stages of regional path creation in the context of TRs and socio-technical system change. In particular we are interested in gaining a greater understanding of how different, and often conflicting, regional interest are unified and mobilized towards new path creation.
- How the specific characteristics of technologies and their potential to create new industrial growth paths influence the dynamics of path creation.
- How the multi-scalar character of TEPs and ST transitions influence the ability of agency to formulate regional strategies.

METHODOLOGY

The analysis focuses on the experience of system change from the point of view of Paper Province (PP), Värmland region's cluster organization for the bio-economy. The study was carried out following the tradition of 'appreciative theorizing' (Nelson, 1994; Nelson & Winter, 1982), a theory-building approach used in innovation studies that integrates a historical account into the analyses of the role of actors, relationships and processes based on qualitative transformations.

Data for the study was collected in 15 semi-structured interviews with representatives from six firms located in Värmland and representatives from the regional government and Karlstad municipality, Karlstad University and RISE (a network of research and technology organizations which perform industrial research). The large firms interviewed included representatives from a very large paper mill (an MNE) which had recently started allocating significant investments to R&D in *forest-based* bio-materials

at a global level; a very large machine-producer (an MNE) with R&D activity in the region; and a large international consultancy firm with technological expertise. Interviews also took place with the founders of three small, technology, firms experimenting with bio-materials and heat management systems. Interviews with national policymakers included very senior directors from Vinnova (Sweden's national innovation agency) and staff working in a number of regional and industrial-based projects. A representative from the national bio-economy Strategic Innovation Programmes (SIP) was interviewed via video-link. The data collection process included two visits to Vinnova and a one-week visit to Värmland Region to the premisses of PP.

Interviews took place in 2016, three years after PP had won Vinnova's Vinnväxt competition – a process which was generally recognized as initiating the region's strategic shift towards the development of a bio-economy – and therefore focused on the initial stages of a process of regional transition. Interviewees discussed the history, industrial structure, knowledge and competences of the region as well as the character of its industrial networks. The international linkages and activities of regional firms and policymakers featured prominently in interviews given the international character of the region's firms and RIS. The discussion explored in depth the role of agency – above all of PP – in regional path creation. Without prompting, interviewees highlighted the importance of PP in strategy formulation and the alignment of dispersed regional interests which enabled the region to take steps towards new path creation. The data were transcribed and coded to identify the main themes. Given the global nature of the technologies underlying the bio-economy TEP and ST regime we start the analysis by outlining the general characteristics of this technology and the initiatives taken in Sweden to create a radically new national industry based on bio-materials.

THE CHALLENGES OF TRANSITION TO A REGIONAL BIO-ECONOMY IN SWEDEN'S VÄRMLAND REGION

A bio-economy involves underlying changes to an economy so that renewable biological resources replace fossil fuels to become the major source of energy and raw material for production. Bio-economies are seen as new ST regimes that require the development of new forms of production, new firms, new markets, as well as new institutions. Some new materials and technologies associated with bio-economies also have the potential to become *motive* industries as in Perez (2002, 2010), thereby becoming the basis for many clusters of radically new technologies underpinning present day TRs.

One example of a bio-material with the potential to become a *motive* industry is lignin, a wood component produced as a by-product of pulp production, described as 'the second biggest source of renewable carbon on the planet'.[1] Lignin can potentially be refined into new environmentally friendly fuels, chemicals and lightweight materials with use across numerous industries (Formas, 2012). Lignin has, therefore, been described as the new 'green gold' because of its potential to replace oil as a source of fuel and raw material.[2] There still are, however, high levels of uncertainty regarding the potential success of specific technological trajectories related to lignin, the nature of future markets, the regulatory system and how these factors will impact carrier/user industries. These uncertainties have made some firms reluctant to commit to the long-term, high-capital, investments (e.g., building of large bio-refineries), or R&D and knowledge acquisition expenditures needed to develop this new technology (interviews: PP, SIP bio-economy, R&D managers).

At the time of interviews, niches for experimentation with new bio-materials were being created at various spatial levels. Other high-risk areas of experimentation included the creation of new relationships across industries with no history of collaboration (e.g., the forestry and textile industries). Within Sweden, government funding of Testbeds, understood as collaborative environments where stakeholders experiment with new technological and organizational solutions, were important niche initiatives. Interviews with industry stakeholders indicate that collective industry-level expectations and visions regarding the potential of these new technologies were being developed within these global, national and regional *niche* environments (interviews various: PP, SIP bio-economy, R&D managers).

A novel and critical element in Sweden's approach to innovation policy since the Lund declaration of 2009,[3] is the link established between national science, technology and innovation (STI) strategy and the need to address the United Nation's Sustainable Development Goals (SDGs).[4] National innovation policy, therefore, attempts to strengthen Sweden's international competitiveness and shape future business development by directing national investment and technological development activities towards finding sustainable solutions to societal challenges. Interviews indicate that Vinnova sees the mobilization of different stakeholder groups behind *challenge-driven innovation strategies* as critical to regional and industrial *system change*. Two major programmes associated with ST system transition are the regionally based Vinnväxt programmes and the industry-based SIPs. These policy initiatives are closely aligned with European Union (EU) industrial and innovation policy.

PROCESS OF TRANSITION TOWARDS A BIO-ECONOMY IN THE VÄRMLAND REGION

Sweden's Värmland Region has a long history of industrial development based on the processing of forest-based raw materials – above all pulp and paper – and deep knowledge of the process technologies underlying these industries. At the time of this study, some 200 companies linked to the pulp and paper industry existed in the region covering the whole value-chain. The majority of the large mills and supplier firms were the local affiliates of leading MNEs and a number of them were also the main global

innovators in the industry. The region hosts a cluster organization – Paper Province (PP) – with more than 100 member companies. PP's management board includes representatives from the large MNEs, a number of technology-based SMEs, the regional government of Värmland, the municipal government of Karlstad, the University of Karlstad, and the regional RISE centre. The Värmland's region's RIS can be described as a thick and specialized RIS. At the time of interviews, the region was in the very early stages of a process of ST transition with the potential to create new regional growth paths based on forest-based bio-materials. Innovative projects in the regions include LignoCity2.0, a testbed and R&D centre on the applications of lignin; Bioinno, a testing environment for large-scale bio-composite prototypes on 3D printers; FFLAM, a test bed for fossil free laminates; as well the opening of R&D facilities by paper mills such as Stora Enso.

The initial process of transition towards a regional bio-economy can be traced back to the mid-to-late 2000s when the Värmland regional government began to push regional cluster organizations such as PP to adopt a more strategic role in regional industrial development. This role required the identification of specific paths of regional development and the introduction of policy initiatives that gave direction to processes of change.

> [W]e wanted to challenge the clusters, because they tend to work more with generic problems, or issues for the industry like the supply of competence or business development. But we wanted also to take a more strategic direction for the cluster, what kind of development and renewal do they want to move into? And it's hard to do that work when you have a number of industrial people around the table.
>
> (regional government)

Several important initiatives to stimulate investment in innovation in bio-economy based activities were taken by PP in the mid-2000s including the establishment of a demonstration plant for the development of lignin. Efforts towards a deeper transformation of the local economy, however, were not successful during this period because the large paper and pulp MNEs in the region could not agree on a common strategy (interview: PP). One of the main obstacles to change at this stage was the fact that packaging, the main business of the regional pulp and paper mills, was still experiencing growth. The main incumbent firms, therefore, did not see the need to invest in experimental technologies not connected to their main businesses. During this period the view of many mills was that you couldn't make money from lignin (interview: regional government). What existed in the region, therefore, was a strongly embedded ST system with no clear incentive for change from a business point of view. During this period, the lack of alignment between the main MNEs in the region who had no interest in change and regional policymakers, who were under pressure to develop new local growth paths, was a significant obstacle to structural change.

Arguments in favour of industrial diversification towards a regional bio-economy began to gain increasing support amongst the paper and pulp MNEs from 2012 to 2013 when questions – at local and global levels – regarding the long-term commercial sustainability of their dominant business models became widespread. The worsening of business conditions was the result of both a fall in the global consumption of paper as well as an increasing awareness of the industry's negative environmental impact by policymakers within Sweden and the EU.

Interviews with regional firms and policymakers indicate that this change in business conditions was critical for the creation of a more receptive environment to arguments in favour of new regional growth path and the acceptance of new 'visions' that opened the way to the notion of a *forest-based bio-economy*. As the global demand for forest raw materials decreased, the traditional pulp and paper firms within PP began to accept the opening of the cluster organization to bio-materials and bio-energy companies. Opening the membership of PP exposed these firms to new *visions* including the potential of new bio-materials produced from their waste-products (interviews regional and municipal governments, PP, paper mill, technology SME, RISE). What we see in Värmland region during this period is that, though critical elements of the knowledge, networks and infrastructure that would enable a transition towards a bio-economy existed in the area, and support for change had begun to grow, a common regional strategy able to mobilize and give directionality to the activities and investment of local firms was missing. Within the region, the challenges associated with creating an alignment of different stakeholder interests around a common strategy for industrial renewal and ST transitions were significant. One of the main difficulties was the inability of regional MNEs affiliates to take strategic decisions. These decisions are usually made at headquarter level and are driven by considerations which are far removed from the needs of regions. Though local management often supported strategies for regional growth based on a shift towards a bio-economy, proposals for change were blocked by headquarters which had different priorities and perceptions of the needs of the whole MNEs. Moreover, though local suppliers and service providers often welcome the idea of change, there was also concern that system change would disrupt local collaborative buyer–supplier relationships.

In the case of Värmland, the deadlock was broken when, under pressure from Vinnova, the leadership of PP in collaboration with the regional government, were able to formulate a new strategy of regional renewal based on the notion of *building a regional innovation environment based on a forest-based bio-economy* (interview: PP). The critical idea was the transformation of the regional economy into a '*practical demonstrator*' of a bio-economy based on new materials – above all lignin – developed from the forest. Over a short period of time, the notion that waste material from paper and pulp production could become the basis for the creation of new, globally

competitive, regional value-chains won the support of MNE headquarters who agreed to use regional facilities to monitor new technological developments.

A critical element that stimulated the formulation of a regional renewal strategy and forced the PP leadership to think about the long-term future of the region was the application in 2010 to Vinnova's 10-year Vinnväxt programme; the programme stipulates that a portion of funds be spent on environmental projects. Discussions around the Vinnväxt competition opened a period collective search within PP's management board for an environmentally sustainable regional growth strategy. The discussions revealed that the paper mills and their suppliers could not identify renewable resources in the local economy and had no clear idea of possible alternative growth paths based on forest-based new materials such as lignin.

> We did a workshop, a SWOT analysis. Very simple, I remember that they [the mills and suppliers] could tell a lot of threats and they could identify a lot of strengths. But in the possibility area, there was almost nothing.
>
> (interview: PP)

In their efforts to develop a strategy compatible with the Vinnväxt requirements, the leadership of PP came across the notion of a '*forest-based bio-economy*', a concept which opened a scenario of regional ST transitions compatible with the existing business interests of the paper and pulp MNEs. In a *forest-based bio-economy,* the production of paper and pulp would remain an important part of the regional economy but the industry's waste products – namely lignin and heat – would become the raw materials for new regional value-chains. Moreover, the deep knowledge and capabilities of the process technologies that underpin innovation in forest-based production ensured that existing mills would be key players in the new ST regime (interviews: PP, regional R&D managers). The articulation of a long-term strategy for regional growth based on a radically new ST regime aligned with the long-term business interest of MNEs in the region proved critical to gaining the support of global senior managers of these firms and unified the various stakeholder interests around a new vision of system change.

> [I]t was a lot about convincing PP's management board about the possibilities of the forest bio-economy, so when I look back, I think it was about selling a good story about the future. That the forest, that has been our history, is now our future … to have a story was the key, to have a vision of what you wanted to do.
>
> (interview: PP)

STRATEGY, DIRECTIONALITY AND AGENCY

Within the PP management board, the organizations that played a critical role as agents of regional system change were: the leading paper mills and machine producers, the Värmland regional government, and the municipality. The role of Vinnova through the Vinnväxt programme was also critical. We discuss these in turn:

Paper and pulp MNEs

Most of the paper and pulp mills have a long history in the area (in some cases 50–100 years) and are a critical part of the knowledge and competence-base of the region. As MNEs, these mills are also embedded in the global knowledge-systems and innovation networks of their parent firms. These mills have significant power over the regional economy through their direct investment, their control over regional value-chains and their voice in the regional institutional and political system. In organizationally thick and specialized RIS these firms are critical to system change as they can mobilize significant resources and create new networks. However, as the example of Värmland shows, regional affiliates do not determine company strategies so their ability to bring about system change is determined by the degree of alignment between regional strategies and the global strategies of parent firms.

Suppliers and technology firms

Other large companies in the region such as machine suppliers, technology-SMEs and technology consultancy firms were very open to the possibility of novel bio-based growth paths, however, their dependence on the large paper and pulp MNEs for their business limited their capacity for agency. Therefore, while these firms have the knowledge to play a critical role in regional ST transitions, their role as systems-agents can be limited.

The cluster organization

One critical element mentioned by all firms interviewed was how the existence of PP enabled firms to meet, discuss, and develop a collective strategy (interviews: paper mill, machine producer). In the case of the MNEs, our interviews indicate that their participation in PP's management board enabled the adoption of strategies favouring the shift towards a bio-economy. An interviewee from one of the main paper mills highlighted the importance of PP as follows:

> We were very early to actually put the bio-economy on the agenda, in the board and in the meetings and everywhere, to really have that as a strategy. So, I think we were four or five years earlier than everybody else … we were very early adopters of this, as a strategy. This is the thing.
>
> (interview: major paper mill)

Moreover, the important role played by the leadership of PP was explained thus:

> It's good to have someone in this cluster that listens and transforms and have a strategy and align us together, because of course, we are a lot stronger together.
>
> (interview: major paper mill)

Local policymakers expressed their views as follows:

> The work that PP did to bring people together … this changed the way a lot of companies look at the bio-economy. … It opened the eyes to the idea that waste-streams and side-streams, which were seen as costs, can be valuable materials … not everyone can draw up a strategy for how a bio-economy should be implemented here, to understand what it means here, and I think PP was responsible for this. They have been important in defining the concept of a bio-economy for the region.
>
> (interview: municipal government)

The state

In the case of the Värmland's region, the initial push for the development of strategies for path creation came from the government and policymaking system.

Regional government

As a member of PP's management board, the Värmland regional government played a central role in the formulation and development of PP's strategy for regional ST transition towards a forest-based bio-economy. The contribution of the Värmland regional government was strongly influenced by its close engagement with EU policy for cluster development and Smart Specialisation. PP's knowledge of Värmland's RIS and the changes required to bring about a ST transitions to a bio-economy were developed in response to the regional government's Smart Specialisation initiatives. Moreover, the initial search for a local strategy for growth by PP was in response to the regional government's challenge to regional cluster organizations to assume a more strategic role in their regions (interviews: PP, Värmland regional government).

National government

National government through the Vinnväxt programme was a major change-agent behind Värmland ST transition towards a forest-based bio-economy. In line with national policy supporting innovation strategies that address societal challenges, funds from Vinnväxt programmes have to be allocated to support the development of renewable technologies (interviews: PP, Vinnova). This requirement directed PP's search for a new regional growth path towards the notion of a forest-based-bio-economy.

CONCLUSIONS

By focusing the analysis on the processes of system change the discussion has shed light into the complex, contested and negotiated character of regional transitions motivated by the emergence of radically new Industry 4.0+ technologies. This is particularly true in the initial stages of TRs and radically new ST regimes when the technologies with the potential to open new trajectories of regional growth are not well understood, do not obviously fit existing business models, are expensive and associated with technological, market and institutional uncertainty. The lack of motivation by powerful incumbent firms which have the resources but lack the strategic vision for system change can hinder processes of regional rejuvenation. It is significant that even in a region with such favourable conditions for new path creation the motivation for system change was initially absent.

The experience of the Värmland region indicates that a combination of three conditions may be necessary to break potential deadlocks. First, changes in global business conditions (or new requirements for competitiveness) that raised question about the sustainability of existing business models may be required for system change. This is critical as it prompts a search for alternatives by powerful incumbents with the resources to undertake these large investments. The second condition is the existence within regional economies of the key factors (e.g., knowledge, raw materials, relevant networks) needed for path creation. The third condition is the existence of regional actors capable of articulating a vision and formulating a strategy able to align key regional interests and mobilize resources towards new path creation based on regional resources. The experience of Värmland region suggests that regional policy bodies with an understanding of the key characteristics and requirements of the technologies driving TRs and new ST regimes and able to formulate regional strategies that take advantage of their potential for growth is necessary, though not sufficient, for new path creation.

The ability to formulate unifying strategies for regional stakeholders raises important questions regarding system-level agency. Dominant regional firms can mobilize resources, access external knowledge and innovation networks, and reconfigure local supply chains spearheading processes of regional transition. Powerful firms will only play the role of system agents, however, if new regional growth paths are aligned with their long-term interests and global corporate strategies. The danger of misalignments are greater when MNEs are not well anchored in regional economies and when regional capabilities are not critical to the main business model of MNEs. The study also indicates that suppliers and technology-based firms would find it difficult to play the role of change agents in system transitions in the face of opposition from dominant firms given their condition of dependency.

In the case of Värmland region a key factor of success is the accumulated knowledge, capabilities and infrastructural investment in lignin – a potential replacement for fossil based raw materials and fuel and therefore the basis for a transformational shift in the techno-socio-economic paradigm attuned to a green economy associated with the notion of Industry 4.0+. Though the new bio-based TEP and ST regime is the product of advances in scientific knowledge of a global nature, the existence of deep regional knowledge of bio-processing production has been critical to emerging system change and the creation of radically new growth paths. The potential of lignin to become a motive industry in the next TR stimulating the development of carrier industries in the region, is a key factor facilitating the process of regional strategic alignment. This highlights the need for regional

scholars to develop an understanding of the critical characteristics of the technologies driving TRs and ST transitions and influence the potential for new growth paths in regions.

The processes of ST transition towards a bio-economy in the Värmland region are part of a broader process of TR and ST transition that is unfolding at different spatial scales. Though in Värmland these processes are being shaped by very specific regional factors, they have also been strongly influenced by national, EU, and international business and policy systems showing the fluidity of different spatial domains. Leading firms are deeply embedded in the region but also in the business and knowledge networks of their parent companies. The strategic decisions of these firms are not driven by regional concerns, however, the experience of the Värmland region suggests that MNE-wide strategic shifts can be influenced by regional strategies. At policy level both the regional government and the leadership of PP have been strongly influenced by initiatives at both EU and national level. At the same time, PP and the paper mills have contributed to the formulation of national industrial strategies through their participation in the bio-economy SIP. This suggests that studies with an exclusive focus on regional agency and local factors as drivers for change do not give an accurate account of the present-day processes of regional system change.

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NOTES

1. See https://www.storaenso.com/en/products/lignin.
2. See https://www.storaenso.com/en/products/lignin.
3. See https://cordis.europa.eu/article/id/31013-swedish-presidency-research-must-focus-on-grand-challenges.
4. See https://www.government.se/press-releases/2016/11/collaborating-for-knowledge–for-societys-challenges-and-strengthened-competitiveness/.

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